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U.S. Dept. of Transportation, Transportation Systems Center

REPORT NO. DOT-TSC-NHTSA-80-13 DOT-HS-805 224

RESULTS OF ENERGY-LOSS MEASUREMENTS ON PASSENGER CAR TIRES OPERATING IN THE FREE-ROLLING AND BRAKING/TRACTION MODES

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APR 1 1980

FEBRUARY 1980
FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
Office of Research and Development
Washington DC 20590

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TSC-
NHTSA-
80-13

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT-HS-805 224		

4. Title and Subtitle

RESULTS OF ENERGY-LOSS MEASUREMENTS ON PASSENGER CAR TIRES OPERATING IN THE FREE-ROLLING AND BRAKING/TRACTION MODES

5. Report Date: February 1980

6. Performing Organization Code:

8. Performing Organization Report No.: DOT-TSC-NHTSA-80-13

7. Author(s): L. Bogdan

9. Performing Organization Name and Address:
Calspan Advanced Technology Center*
Calspan Corporation
P.O. Box 400
Buffalo NY

10. Work Unit No. (TRAIS): HS027/R0404

11. Contract or Grant No.: DOT-TS-15361 and 15581

13. Type of Report and Period Covered: FINAL REPORT

12. Sponsoring Agency Name and Address:
U.S. Department of Transportation
National Highway Traffic Safety Administration
Office of Research and Development
Washington DC 20590

14. Sponsoring Agency Code:

15. Supplementary Notes

*Under Contract to: U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

16. Abstract

This report described the results of tests on twelve passenger car tires performed on Calspan's Tire Research Facility (TIRF). The tests were used to measure energy loss under three different test conditions: 1) with the tire in a straight, free-rolling condition; 2) with the tires subjected to driving/braking torques required by conformance to the Federal Urban Driving Cycle (LA-4); and 3) with the tires subjected to driving/braking torques required by conformance to the Federal Highway Fuel Economy Test (HFET). The sample set of tires was representative of current original equipment, and ranged in size from a P155/80D13 to an HR78-15.

APR 17 1980

17. Key Words

Tire Energy-Loss Measurement
Free-Rolling Mode
Braking/Traction Mode

18. Distribution Statement

DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	58	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

This report describes the results of tire energy-loss measurement tests performed for the U.S. Department of Transportation, Research and Special Programs Administration, Transportation Systems Center. The program was sponsored by the U.S. Department of Transportation, National Highway Traffic Safety Administration, under PPA-HS027, "Support for Research and Analysis in Auto Fuel Economy and Related Areas."

This report presents an account of the details of the test program, including a discussion of procedural details and methods of data reduction. A summary and an analysis of the test results are included together with tabular listings of the numerical results. Conclusions derived from the test results are itemized.

Test operation were performed under the direction of George A. Tapia Ignaty Gusakov, Manager of the TIRF Center was the overall program manager, and Leonard Bogdan was the project engineer. The author wishes to thank Stephen R. Bobo, the Transportation Systems Center Contract Technical Monitor, for his assistance.

METRIC CONVERSION FACTORS

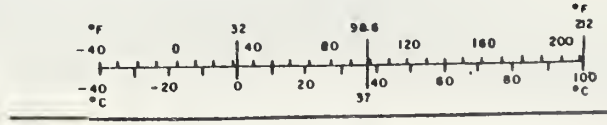
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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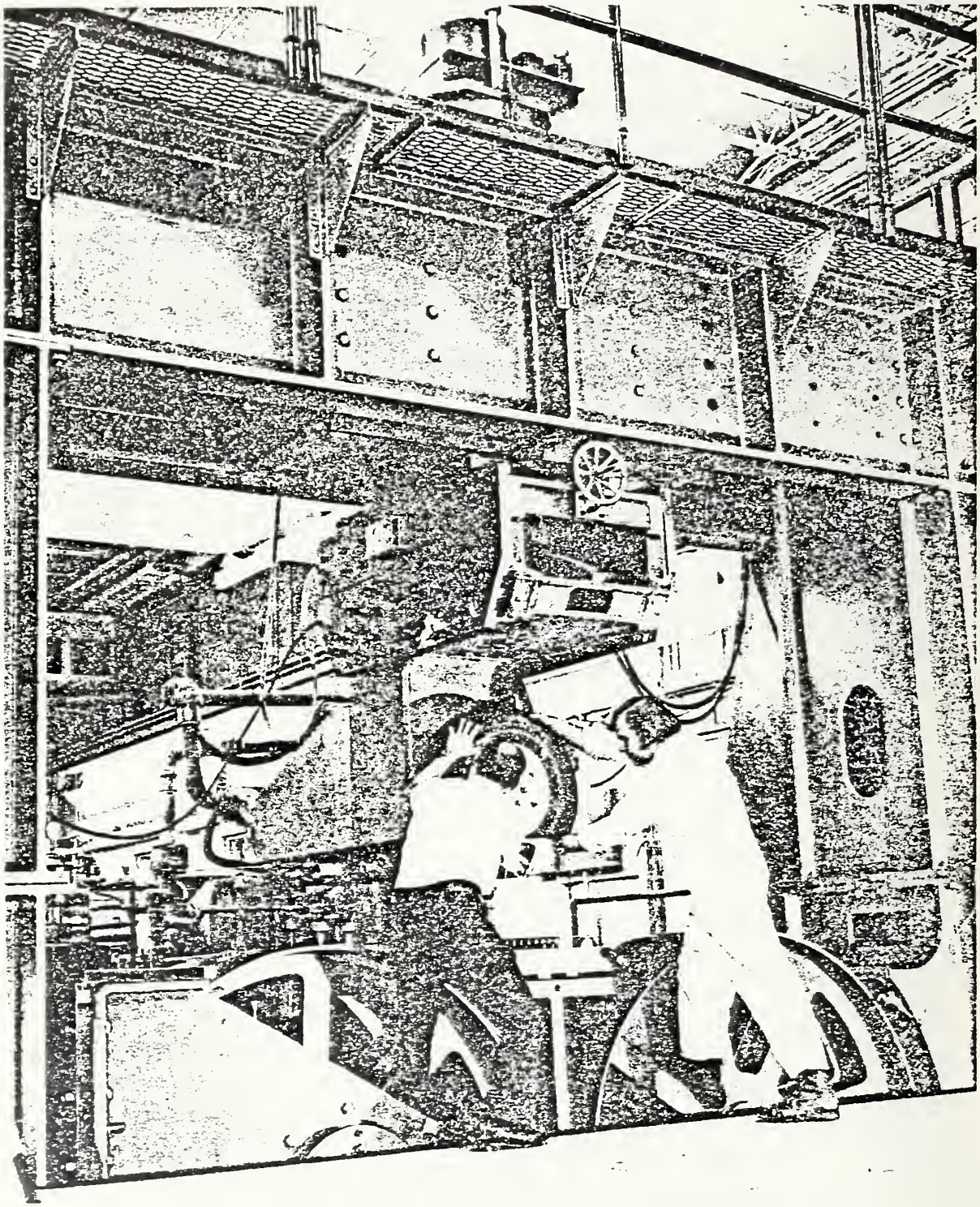
LIST OF ABBREVIATIONS

TIRF	Calspan's Tire Research Facility
LA-4	Federal Urban Driving Cycle
HFET	Federal Highway Economy Test
TPC	General Motors Tire Performance Criteria
CSP	Continuous Sampling Program
FR	Rolling resistance force
BFT	Bearing friction torque
RL	Tire loading radivs
FX	Longitudinal Force
ER	Energy Loss
SR	Slip ratio
CAT	Contained air temperature
TST	Tire Tread surface temperature
BFT	Bearing friction torque
SEM	Scanning Electron Microscope
DAP	Data Acquisition Program



CALSPAN TIRE RESEARCH FACILITY (TIRF)

1. PROGRAM OBJECTIVES

The purpose of this test program was to measure the energy loss for each of twelve passenger car tires selected to be representative of current original equipment. Each tire was operated on a flat-surface roadway under straight, free-rolling conditions and also under driving/braking traction conditions. The traction tests were of two types. One type involved the use of a synthesized wheel-torque schedule, based on the velocity profile of the LA-4 Urban Driving Cycle, computed for a vehicle with a weight equal to twice the applied normal force on the tire. The second type test was similar in all respects except that the velocity profile of the Highway Fuel Economy Test Cycle was used in calculating the wheel-torque schedule.

2. TEST PROGRAM

A concise tabular summary of the entire test program that was conducted on this project is presented in Table 1. Each test is identified by a TIRF run number which consists of three groups of digits. The first group designates the serial run number, the second group the test series and the third group the sponsoring organization. TIRF tire numbers are structured similarly except that the first group of digits designates the serial tire number. Table 1 lists the nominal values of the test parameters and contains a set of explanatory footnotes.

The first twelve tests were steady-state tests with the tire free rolling at a constant load and a velocity of 50 mph. Normal loads equal to 80% of the T&RA rated load at an inflation pressure of 24 psi were used for all tests. Inflation pressures were capped and permitted to rise during the course of the test. A test duration of 30 minutes was employed for these steady-state tests since experience has shown this time period is sufficiently long to permit stabilization of the tire rolling resistance force.

The final twenty-four tests were devoted to the traction tests, twelve were for the LA-4 cycle and twelve for the HFET cycle. The former was 1370 seconds in duration while the latter was 765 seconds. Details of the methodology used in determining the velocity-torque schedule for each cycle are given in Section 3 while Appendix A contains a summary of the numerical data.

A listing of the tires tested is shown in Table 2. This table includes information on the TIRF tire number, manufacturer, size, trade name and DOT serial number. The six different tire sizes represented were specified by DOT. Two tires in each tire size specified were tested. The two HR78-15 tires were supplied by DOT. The other tires were purchased locally with the aim of achieving a representative sample of current original equipment tires from different vendors.

TABLE 1

TIRE TEST SCHEDULE

Run	Tire	Road Condition*	P psi	V mph	Torque	SA deg.	IA deg.	Load lb.	Comments
1-6-6	2-6-6	Flat, Dry	24	50	Free Rolling	0	0	840	30-Min. Test
2	3							840	
3	5							1024	
4	8							1024	
5	9							784	
6	4							784	
7	1							660	
8	10							660	
9	11							1024	
10	12							1024	
11	6							1208	
12	7							1208	
13	1			(1)	(1)			660	LA-4 Test Cycle
14	10							660	
15	9							784	
16	4							784	
18	3							840	
19	5							1024	
20	8							1024	
21	11							1024	
22	12							1024	
23	7							1208	
24	2							840	
25	6							1208	

* Skid No. = 85

NOTE: Runs No. 1 → 12 were steady-state tests, 30 min. duration

VELOCITY SCHEDULE (1): Urban driving (LA-4) Test Cycle (1370 sec.)

TORQUE SCHEDULE (1): Based on calculations of requirements for a vehicle weight equal to twice the tire load to follow the LA-4 velocity schedule

TABLE 1 (Cont.)

TIRE TEST SCHEDULE

Run	Tire	Road Condition*	P psi	V mph	Torque	SA deg.	IA deg.	Load lb.	Comments
26-6-6	1-6-6	Flat, Dry	24	(2)	(2)	0	0	660	HFET Test Cycle
27	10							660	
28	9							784	
29	4							784	
30	2							840	
31	3							840	
32	5							1024	
33	8								
34	11								
35	12								
36	6							1208	
37	7							1208	

* Skid No. = 85

VELOCITY SCHEDULE (2): Highway Fuel Economy Test (HFET) Cycle (765 sec.)

TORQUE SCHEDULE (2): Based on calculated requirements for a vehicle weight equal to twice the tire load to follow the HFET schedule

SUMMARY OF RIM WIDTHS USED:

P155/80D13 → 4.5"

CR78-14 → 5.0"

FR78-14/15 → 5.5"

HR78-15 → 6.0"

SYMBOL	DEFINITION
P	Inflation Pressure
V	Velocity
SA	Slip Angle
IA	Inclination Angle

TABLE 2

TIRE IDENTIFICATION SCHEDULE

TIRF Tire No.	Manufacturer	Size	Tire Description	DOT - Serial No.	Other Identification
1-6-6	General	P155/80D13	JUMBO BIAS 780	ACE4 EAA 217	
2-6-6	Firestone	CR78-14	STEEL RADIAL 721	VC12 XM3 167	
3-6-6	Goodyear	CR78-14	CUSTOM POLYSTEEL RADIAL	MKL2 HCL 207	
4-6-6	Firestone	BR78-13	STEEL RADIAL 721	YJF 8147	
5-6-6	Goodyear	FR78-14	POLYGLAS II RADIAL	MKL8 H2H 068	E021
6-6-6	Cordovan	HR78-15	BONNEVILLE STEEL RADIAL	PJVY CE9 406	
7-6-6	Avalon	HR78-15	STEEL BELTED RADIAL	JFVY ACE 486	
8-6-6	Michelin	FR78-14	RADIAL	FNL8 A7NX 414	VTY 161543
9-6-6	B.F. Goodrich	BR78-13	LIFESAVER 78 RADIAL STEEL XLM	BEFW MV1 118	
10-6-6	General	P155/80D13	JUMBO BIAS 780	ACE4 EAA 217	
11-6-6	General	FR78-15	JET RADIAL	ACVU WNA 337	
12-6-6	General	FR78-15	JET RADIAL	ACVU WNA 317	

3. TEST DETAILS

The calculation of the energy loss in tires requires that data measurements be made continuously during the course of each test. Inasmuch as the TIRF computer is limited to approximately 600 data points for each channel of data per run, the data sampling rate must be adjusted for each test so that this constraint is accommodated. Thus, the longer the test duration. the longer must be the time interval between successive samples of data.

Of the three types of tests used during this program, the longest in duration was the 30-minute, steady-state test schedule. Since the independent variables were held constant and the dependent variables changed very slowly, a coarse sampling rate could be accepted. Accordingly, a sampling rate of one sample every four seconds was used. The LA-4 cycle is approximately 1370 seconds in length and also includes many rapid changes in velocity. As a consequence, the objective was to obtain maximum resolution by using the full storage capability of the computer. To achieve this end, the sampling rate selected was one sample every 2.2 seconds. On the other hand, the HFET cycle, which is approximately 670 seconds long, has relatively few velocity changes of appreciable magnitude. Thus a convenient sampling interval of two seconds between successive data samples was selected.

For the two different cycle tests, it was necessary to calculate the torque that would have to be applied to each tire to accelerate/decelerate the mass of a vehicle according to the velocity/time schedule specified for that cycle. The simulated vehicle weight used in making the force calculation was chosen to be equal to twice the tire normal load. Data for the values of the tire loaded radius, required for the torque calculation, were obtained from the steady-state tests that were scheduled to be conducted first for this reason (see data in Table 3).

Accelerations, forces and torques were calculated for each time increment. For the LA-4 cycle, linear interpolations of the velocity/time data, listed at one-second intervals in the Federal Register, were used to obtain velocity values at the 2.2-second intervals. A summary of these data is given in Appendix A.

For operational convenience, the torque data were calculated for one standard condition of weight (1000 lb.) and one tire loaded radius (1.0 ft.). This expedient permitted the use of a single card deck to input the test command data to the TIRF computer for any one cycle. Scaling factors in the computer were adjusted to obtain the desired torque level for each individual tire based on its normal load and loaded radius.

Note that the calculated torques account only for the inertial forces involved in accelerating and declerating the simulated weight. This simulation is obviously unrealistic since at a constant test velocity the command torque is zero. Forces associated with rolling resistance and vehicle aerodynamic drag could have been included in the torque calculations but were deliberately excluded by design.

All of the tires were in a new condition when received and each one was therefore subjected to a break-in procedure. For this purpose, the General Motors Tire Performance Criteria (TPC) break-in procedure was employed. The details of this procedure are outlined in Appendix B.

The entire test program was conducted in the continuous sampling program (CSP) mode of operation wherein a software system controls machine operation and continuously logs data. To improve the quality of the measured data, the raw analog signals were conditioned using low-pass electrical filters. Filters having a corner frequency of 0.083 Hz were used for the steady-state tests and 1.0-Hz filters were employed for the driving-cycle tests.

Tire contained air temperature was sensed by a thermistor temperature probe that was inserted through the wheel rim into the approximate center of the tire internal cavity. Tread surface temperature, taken at the approximate center of the tread, was measured with an infrared radiometer.

4. TEST RESULTS

Test data from the steady-state runs were reduced in two different ways so as to obtain values for tire rolling resistance force and tire energy loss. The relation used to calculate rolling resistance is given below.

$$FR = -FX + \frac{BFT}{RL} \tag{1}$$

where FR is the rolling resistance force in lbs., FX is the longitudinal force in lbs., BFT is the bearing friction torque in ft-lbs. and RL is the tire loaded radius in ft. Forces and moments used are consistent in designation and sign with the SAE convention for the tire axis system (Reference 1).

Energy-loss calculations were made using the following equation:

$$ER = -FX + \frac{BFT}{RL}(1 + SR) \tag{2}$$

where ER is the energy loss in ft-lbs. per ft. and SR is the slip ratio. Slip ratio, in this report, is defined as follows:

$$SR = \frac{N \times RL}{k \times V} - 1 \tag{3}$$

where N is wheel rotational speed in rpm, V is the velocity in mph and k is a constant to make the units consistent and is equal to 14.01.

Numerical data for FR and ER were calculated for each sample of data taken. In the case of FR, the equilibrium value of FR, taken as that value measured when the tire has attained thermal equilibrium, was obtained by taking the mean of the final 20 values calculated during the test run. The final value of FR has been corrected for electrical zero drifts in the TIRF balance which affect FX and BFT data. While these zero drifts are small, they can have a sizable effect on the sensitive rolling resistance measurements. A summary of the FR data is given in Table 3. Shown also, is the sample standard deviation, s, associated with each FR value. In addition,

Table 3 includes the mean equilibrium data for inflation pressure (P), contained air temperature (CAT) tire tread surface temperature (TST) and tire loaded radius (RL).

Values of ER were computed on a point-by-point basis using Equation 2 for the steady-state tests and Equation 4 for the LA-4 and HFET cycle tests,

$$ER = -FX + \frac{T}{RL}(1 + SR) \qquad (4)$$

where T is the applied wheel torque. The mean energy loss for each test was computed as follows. For each time increment, the calculated ER was multiplied by the distance the roadway had travelled in that time interval. These products were then summed and divided by the total distance travelled by the roadway for the entire test. Note that it is not practical to make any corrections for drift in the balance electrical signals in the ER calculations. This condition results from the fact that the electrical drifts are assessed only at the conclusion of a test run (all signal channels are set to zero prior to each run) while the ER calculations are made throughout the entire run. Since experience shows that the drift tends to be random in sign and magnitude, the presence of this factor in the data must be noted in comparing test results within and among tires.

Table 4 contains a summary of the mean energy loss (ER) for each tire for the three different test conditions employed, i.e. the steady-state tests, the HFET-cycle tests and the LA-4 cycle tests. Under the steady-state heading in the table, two columns are listed. The numbers in parentheses represent the mean equilibrium ER value taken over the last 20 data samples in the test run. In contrast with all other ER calculations, these data have been corrected for any thermal drifts in the balance signals.

The data shown in Tables 3 and 4 show that the numerical values for most tires increase in level in the following sequence: FR, ER steady state (equilibrium), ER steady state, ER HFET cycle and ER LA-4 cycle. A summary of the relative performance of the tires within and among the different test

TABLE 3

SUMMARY OF EQUILIBRIUM DATA FOR ROLLING RESISTANCE FORCE AND OTHER TEST VARIABLES FOR THE STEADY-STATE TEST RUNS, PASSENGER CAR TIRES

RUN NO.	TIRE NO.	TIRE SIZE	MANUFACTURER	LOAD, lb.	FR, lb.	s*	FR/FZ	P, psi	CAT, °C	TST, °C	RL, in.
7-6-6	1-6-6	P155/80D13	1	667	9.04	0.08	1.36×10^{-2}	27.4	44.0	32.9	10.91
8	10	P155/80D13	1	667	9.15	0.06	1.37	27.2	47.4	31.9	10.90
6	4	BR78-13	2	793	10.69	0.10	1.35	27.7	45.4	32.8	11.25
5	9	BR78-13	3	796	9.67	0.10	1.21	26.6	42.9	34.2	11.07
1	2	CR78-14	2	847	11.40	0.08	1.35	27.8	45.9	29.2	11.65
2	3	CR78-14	4	852	9.50	0.07	1.12	26.8	39.3	30.3	11.48
3	5	FR78-14	4	1034	11.36	0.06	1.10	27.1	43.3	29.7	12.03
4	8	FR78-14	5	1033	11.64**	0.08	1.13	27.0	44.9	35.3	12. 6
9	11	FR78-15	1	1035	10.44	0.06	1.01	27.0	40.8	28.0	12.43
10	12	FR78-15	1	1038	10.92	0.05	1.05	27.0	42.6	29.8	12.42
11	6	HR78-15	6	1218	11.98	0.12	0.98	27.1	42.3	32.5	12.83
12	7	HR78-15	7	1225	10.79	0.11	0.88	26.7	40.2	29.2	13.01

* s = sample standard deviation (FR) ** A replicate test resulted in a value of 11.29 lb.

MANUFACTURER LEGEND: 1 GENERAL, 2 FIRESTONE, 3 B.F. GOODRICH, 4 GOODYEAR, 5 MICHELIN, 6 CORDOVAN, 7 AVALON

TABLE 4

SUMMARY OF MEAN ENERGY LOSS DATA AS DETERMINED FOR STEADY-STATE, URBAN DRIVING CYCLE (LA-4) AND HIGHWAY FUEL ECONOMY (HFET) TESTS, PASSENGER CAR TIRES

TIRF TIRE NO.	TIRE SIZE	MANUFACTURER	BRAND	NORMAL LOAD, lb.	ER, ft-lb/ft		
					STEADY STATE*	LA-4	HFET
1-6-6	P155/80D13	GENERAL	JUMBO BIAS 780	667	9.41 (9.12)	10.60	9.63
10	P155/80D13	GENERAL	JUMBO BIAS 780	667	9.29 (9.23)	10.71	10.25
4	BR78-13	FIRESTONE	STEEL RADIAL 721	793	11.60 (10.84)	14.84	12.51
9	BR78-13	B.F.GOODRICH	RADIAL STEEL XLM	796	9.90 (9.83)	11.63	11.36
2	CR78-14	FIRESTONE	STEEL RADIAL 721	847	11.88 (11.50)	14.73	14.78
3	CR78-14	GOODYEAR	CUSTOM POLYSTEEL	852	9.63 (9.68)	13.03	11.63
5	FR78-14	GOODYEAR	POLYGLAS II	1034	11.98 (11.55)	14.10	11.72
8	FR78-14	MICHELIN	RADIAL	1033	12.41 (11.80)	13.84	13.14
11	FR78-15	GENERAL	JET RADIAL	1035	10.68 (10.59)	13.19	11.47
12	FR78-15	GENERAL	JET RADIAL	1038	11.40 (11.08)	14.58	11.77
6	HR78-15	CORDOVAN	BONNEVILLE	1218	12.37 (12.12)	14.40	14.61
7	HR78-15	AVALON	STEEL BELTED RADIAL	1225	11.26 (10.94)	14.29	11.17

NOTE: Simulated vehicle mass for LA-4 and HFET tests was based on a weight equal to twice the tire normal load.

* Numbers in parentheses are equilibrium values

procedures is shown in Table 5. In Table 5 the ranking of each tire is indicated for each of the five measures of rolling losses which were calculated. Please note that no attempt has been made to normalize the data with respect to normal load so that smaller-size tires tend to rank higher (i.e. have lower losses) than larger-size tires. The objective has been to ascertain whether significantly different rankings would result from different test schedules that include free-rolling and traction-type test conditions. Table 5 was prepared by listing the tires in increasing order of the measured rolling resistance force, FR. In each of the other four columns, the ranking of the tire in that particular category is indicated by a rank number. Steady-test results are seen to be extremely well correlated with only minor shifts in ranking among the three columns. With a few exceptions, the LA-4 and HFET data are also well correlated and correlate quite well with the steady-state rankings. In general, except for some obvious exceptions, it appears that these tires preserve their relative ranking regardless of the type of test or the loss criterion that is used in evaluating tire performance. Note must be made of the fact that ten of the twelve tires tested were of radial-ply construction so that extrapolation of these results to other constructions may be hazardous.

A note of caution needs to be sounded concerning the numerical values of the tire energy-loss data calculated for the LA-4 and HFET cycle tests. Results from tests performed outside of the scope of this program have demonstrated that the transient response characteristics of the wheel-torque servo have a very large effect on the numerical values of the measured tire energy loss. The reason for this situation is that the relation used for calculating energy loss (eq. 4) contains the slip-ratio term, which due to tire compliance, is very sensitive to the time rate of change of the applied torque. Since the torque commands to the TIRF servo are in the form of step-type inputs, updated every 2.2 seconds, the servo transient response is continually being excited. If the overall servo response* is underdamped (highly oscillatory), the fidelity of servo torque output relative to the torque command will be poor. As a consequence, large levels of energy loss may be measured.

* Includes tire characteristics

TABLE 5

TIRE RANKINGS BASED ON VARIOUS ROLLING LOSS CRITERIA
AND TEST SCHEDULES

TIRE NUMBER	MANUFAC-TURER	TIRE SIZE	Ranking				
			Steady-State			LA-4	HFET
			FR*	ER*	ER	ER	ER
1-6-6	GENERAL	P155/80D13	1	1	2	1	1
10	GENERAL	P155/80D13	2	2	1	2	2
3	GOODYEAR	CR78-14	3	3	3	4	6
9	GOODRICH	BR78-13	4	4	4	3	4
11	GENERAL	FR78-15	5	5	5	5	5
4	FIRESTONE	BR78-13	6	6	8	12	9
7	AVALON	HR78-15	7	7	6	8	3
12	GENERAL	FR78-15	8	8	8	10	8
5	GOODYEAR	FR78-14	9	10	10	7	7
2	FIRESTONE	CR78-14	10	9	9	11	12
8	MICHELIN	FR78-14	11	11	12	6	10
6	CORDOVAN	HR78-15	12	12	11	9	11

* Equilibrium values are used in determining rankings.

In adapting the TIRF machine to cycle-type testing, the nominal longitudinal slip servo has been converted into a wheel-torque servo. Because the principal demand on the torque servo has been in static operation, this servo has a low loop gain and a highly underdamped transient response. In normal operation, several seconds are permitted for the servo transient response to decay before computer acquisition of data takes place.

For cycle testing, the practice has been to reduce servo loop gain further to modify the transient response. The attempt is made to achieve 0.7 of critical damping, a widely used servo criterion which provides the best compromise between rapid response and minimum oscillatory overshoot in response to a step forcing function. The gain method of modifying servo response has been used because it is simple to implement. However, it is not a fully satisfactory technique since static accuracy and response time are compromised. Other servo damping techniques are available that permit the use of high loop gains but to have made use of these methods would have required extensive and costly rework of TIRF circuitry.

As the result of an oversight, the initial cycle tests on the tires listed in Table 2 were made with the torque-servo gain at its nominal level. For purposes of comparison, the energy loss data obtained for several selected tires for LA-4 and HFET cycles are shown below in Table 6 for the situations where the torque servo was poorly damped and where it was well damped. The ranking of the tires in this small sample was unchanged despite the differences in servo response.

TABLE 6

EFFECT OF TORQUE SERVO RESPONSE ON
MEASURED ENERGY LOSS IN PASSENGER TIRES

		ER, ft-lb/ft			
TIRE	LOAD	Servo Underdamped		Servo Damped	
SIZE	LB.	LA-4	HFET	LA-4	HFET
P155/80D13	667	18.40	15.48	10.60	9.63
FR78-14	1034	19.75	21.09	14.10	11.72
FR78-15	1035	19.38	19.33	13.19	11.47

The data of Table 6 demonstrate the large sensitivity of measured tire energy losses to torque servo characteristics. In view of this fact, it would be clearly desirable to use servo longitudinal force rather than wheel torque in performing cycle-type tests for the purpose of determining tire energy losses. This approach could present some complex servo stability problems since tire circumferential compliances and nonlinear slip would now be inside the servo loop.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on energy-loss measurements made on a set of twelve passenger car tires ranging in size from P155/80D13 to HR78-15, the following conclusions are warranted.

1. Energy-loss values for a given tire are, in general, the smallest for steady-state, free-rolling test conditions and the largest for the driving/braking traction conditions of the LA-4 test cycle.

2. Relative ranking among tires with respect to energy-loss level appears to be relatively independent of the type of test cycle that is employed.

3. Energy-loss levels measured under conditions of driving/braking traction are very sensitive to the magnitude and duration of the time rate of change of the applied wheel torque.

In future testing of the type performed in the course of this program, it is recommended that the following suggestions be accorded serious consideration.

1. The calculated wheel torques for the LA-4 and HFET test cycles should be augmented to include vehicle aerodynamic drag and the rolling resistance force of the vehicle's other tire which is free-rolling. The TIRF torque servo should be modified to achieve a well-damped transient response in the presence of a high gain in the servo loop to achieve tighter control of the traction conditions.

2. An experimental study should be initiated to achieve a capability to servo the tire longitudinal force (rather than wheel torque) in performing driving/braking traction tests aimed at determining tire energy-loss levels.

3. More tests on a larger sample of tires should be conducted to provide information that can be statistically evaluated to determine the relationship between tire losses under equilibrium and cycle operation.

6. REFERENCES

1. "Vehicle Dynamics Terminology SAE J670d", SAE Recommended Practice, July 1975.

2. Bird, K. D. and Martin, J. F., "The Calspan Tire Research Facility: Design, Development and Initial Test Results," Presented at SAE Automobile Engineering Meeting, Detroit, Michigan, May 14-18, 1973, SAE Paper No. 730582.

3. Schonfeld, R., "Photo-Interpretation of Pavement Skid Resistance," Ontario Ministry Transportation and Communication Report, RR 188, June 1974.

APPENDIX A

A TABULAR SUMMARY OF THE LA-4 AND HFET VELOCITY-TORQUE SCHEDULES

The velocity-torque-time data that are summarized in this appendix were derived from the basic velocity-time schedules that are specified by the Environmental Protection Agency as a part of the Federal Test Procedure for determining exhaust emissions and fuel economy of light-duty vehicles. Since the data storage capacity of the TIRF minicomputer is limited to approximately 600 points, it was necessary to use coarser time increments than the one-second intervals employed in defining the LA-4 and HFET cycles.

For the LA-4 cycle, the time interval was selected to be 2.2 seconds. Velocities corresponding to these non-standard time increments were obtained by a linear interpolation of the original velocity-time listing. Choice of the 2.2-second interval made maximum use of the available computer storage and thus achieved the best possible fidelity in reproducing the LA-4 schedule in which rapid velocity changes are required. The HFET cycle, on the other hand, is characterized by relatively minor changes in velocity with time so that fewer data samples are required in faithful reproduction of this cycle. Consequently, a 2-second time interval was chosen. Every other time-velocity pair in the original schedule was thus used and no interpolation was required.

A calculation was made of the accelerations required to accomplish the velocity changes specified for each interval of time. Taking an equivalent inertia weight of 1000 lbs. and a tire loaded radius of 1.00 ft., a wheel torque corresponding to each acceleration was calculated.

A listing of the time, velocity, acceleration, force and torque data that served as the basic TIRF computer inputs for the LA-4 and HFET cycle tests is presented in Tables A-1 and A-2, respectively.

TABLE A-1. EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS

WEIGHT = 1000.00LBS
WHEEL RADIUS = 1.00 FT

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME	VELOCITY		ACCELERATION	FORCE	TORQUE
(SEC)	(MPH)	(FPS)	(FT/SEC**2)	(LBS)	(FT*LBS)
0.0	0.0	0.0	0.0	0.0	0.0
2.200	0.0	0.0	0.0	0.0	0.0
4.400	0.0	0.0	0.0	0.0	0.0
6.600	0.0	0.0	0.0	0.0	0.0
8.800	0.0	0.0	0.0	0.0	0.0
11.000	0.0	0.0	0.0	0.0	0.0
13.200	0.0	0.0	0.0	0.0	0.0
15.400	0.0	0.0	0.0	0.0	0.0
17.600	0.0	0.0	0.0	0.0	0.0
19.800	0.0	0.0	0.0	0.0	0.0
22.000	5.900	8.653	3.933	122.153	122.153
24.200	12.100	17.747	4.133	128.364	128.364
26.400	17.000	24.933	3.267	101.449	101.449
28.600	19.700	28.893	1.800	55.900	55.900
30.800	22.200	32.560	1.667	51.760	51.760
33.000	22.100	32.413	-0.067	-2.070	-2.070
35.200	20.800	30.507	-0.867	-26.915	-26.915
37.400	18.700	27.427	-1.400	-43.478	-43.478
39.600	14.900	21.853	-2.533	-78.675	-78.675
41.800	15.400	22.587	0.333	10.352	10.352
44.000	17.100	25.080	1.133	35.197	35.197
46.200	21.400	31.387	2.867	89.027	89.027
48.400	22.800	33.440	0.933	29.986	29.986
50.600	21.000	31.080	-0.800	-24.845	-24.845
52.800	17.500	25.667	-2.733	-84.886	-84.886
55.000	15.800	23.173	-1.133	-35.197	-35.197
57.200	20.200	29.627	2.933	91.097	91.097
59.400	23.600	34.613	2.267	70.394	70.394
61.600	24.800	36.373	0.800	24.845	24.845
63.800	24.700	36.227	-0.067	-2.071	-2.071
66.000	24.700	36.227	0.0	0.0	0.0
68.200	24.700	36.227	0.0	0.0	0.0
70.400	24.800	36.373	0.067	2.071	2.071
72.600	25.600	37.547	0.533	16.563	16.563
74.800	25.000	36.667	-0.400	-12.423	-12.423
77.000	25.400	37.253	0.267	8.282	8.282
79.200	25.900	37.987	0.333	10.352	10.352
81.400	26.300	38.573	0.267	8.282	8.282
83.600	28.200	41.360	1.267	39.337	39.337
85.800	29.700	43.560	1.000	31.056	31.056
88.000	30.400	44.587	0.467	14.493	14.493
90.200	30.700	45.027	0.200	6.211	6.211
92.400	30.300	44.440	-0.267	-8.281	-8.281
94.600	30.600	44.880	0.200	6.211	6.211
96.800	30.000	44.000	-0.400	-12.422	-12.422
99.000	29.800	43.707	-0.133	-4.141	-4.141
101.200	30.700	45.027	0.600	18.633	18.633
103.400	31.000	45.467	0.200	6.211	6.211
105.600	30.000	44.000	-0.667	-20.704	-20.704
107.800	30.100	44.147	0.067	2.070	2.070

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME	VELOCITY		ACCELERATION	FORCE	TORQUE
(SEC)	(MPH)	(FPS)	(FT/SEC**2)	(LBS)	(FT*LBS)
110.000	31.200	45.760	0.733	22.774	22.774
112.200	32.200	47.227	0.667	20.704	20.704
114.400	32.000	46.933	-0.133	-4.141	-4.141
116.600	26.600	39.013	-3.600	-111.801	-111.801
118.800	19.400	28.453	-4.800	-149.068	-149.068
121.000	12.100	17.747	-4.867	-151.138	-151.138
123.200	4.800	7.040	-4.867	-151.139	-151.139
125.400	0.0	0.0	-3.200	-99.379	-99.379
127.600	0.0	0.0	0.0	0.0	0.0
129.800	0.0	0.0	0.0	0.0	0.0
132.000	0.0	0.0	0.0	0.0	0.0
134.200	0.0	0.0	0.0	0.0	0.0
136.400	0.0	0.0	0.0	0.0	0.0
138.600	0.0	0.0	0.0	0.0	0.0
140.800	0.0	0.0	0.0	0.0	0.0
143.000	0.0	0.0	0.0	0.0	0.0
145.200	0.0	0.0	0.0	0.0	0.0
147.400	0.0	0.0	0.0	0.0	0.0
149.600	0.0	0.0	0.0	0.0	0.0
151.800	0.0	0.0	0.0	0.0	0.0
154.000	0.0	0.0	0.0	0.0	0.0
156.200	0.0	0.0	0.0	0.0	0.0
158.400	0.0	0.0	0.0	0.0	0.0
160.600	0.0	0.0	0.0	0.0	0.0
162.800	0.0	0.0	0.0	0.0	0.0
165.000	6.600	9.680	4.400	136.646	136.646
167.200	13.900	20.387	4.867	151.139	151.139
169.400	20.800	30.507	4.600	142.857	142.857
171.600	25.200	36.960	2.933	91.097	91.097
173.800	25.800	37.840	0.400	12.422	12.422
176.000	24.700	36.227	-0.733	-22.774	-22.774
178.200	25.200	36.960	0.333	10.352	10.352
180.400	26.400	38.720	0.800	24.845	24.845
182.600	25.000	36.667	-0.933	-28.985	-28.985
184.800	20.100	29.480	-3.267	-101.449	-101.449
187.000	17.200	25.227	-1.933	-60.042	-60.042
189.200	18.900	27.720	1.133	35.196	35.196
191.400	23.100	33.880	2.800	86.957	86.957
193.600	29.200	42.827	4.067	126.294	126.294
195.800	35.700	52.360	4.333	134.575	134.575
198.000	39.300	57.640	2.400	74.534	74.534
200.200	42.400	62.187	2.067	64.182	64.182
202.400	45.400	66.587	2.000	62.112	62.112
204.600	47.200	69.227	1.200	37.267	37.267
206.800	47.400	69.520	0.133	4.141	4.141
209.000	47.000	68.933	-0.267	-8.281	-8.281
211.200	47.000	68.933	0.0	0.0	0.0
213.400	47.100	69.080	0.067	2.071	2.071
215.600	47.700	69.960	0.400	12.422	12.422
217.800	49.000	71.867	0.867	26.915	26.915

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME	VELOCITY		ACCELERATION	FORCE	TORQUE
(SEC)	(MPH)	(FPS)	(FT/SEC**2)	(LBS)	(FT*LBS)
220.000	50.000	73.333	0.667	20.704	20.704
222.200	51.100	74.947	0.733	22.774	22.774
224.400	52.600	77.147	1.000	31.056	31.056
226.600	54.400	79.787	1.200	37.267	37.267
228.800	55.000	80.667	0.400	12.423	12.423
231.000	54.600	80.080	-0.267	-8.282	-8.282
233.200	54.900	80.520	0.200	6.211	6.211
235.400	55.600	81.547	0.467	14.493	14.493
237.600	56.200	82.427	0.400	12.422	12.422
239.800	56.700	83.160	0.333	10.352	10.352
242.000	56.500	82.867	-0.133	-4.141	-4.141
244.200	56.500	82.867	0.0	0.0	0.0
246.400	56.500	82.867	0.0	0.0	0.0
248.600	56.300	82.573	-0.133	-4.141	-4.141
250.800	55.200	80.960	-0.733	-22.774	-22.774
253.000	54.200	79.493	-0.667	-20.704	-20.704
255.200	53.700	78.760	-0.333	-10.352	-10.352
257.400	53.900	79.053	0.133	4.141	4.141
259.600	54.100	79.347	0.133	4.141	4.141
261.800	53.500	78.467	-0.400	-12.423	-12.423
264.000	52.600	77.147	-0.600	-18.633	-18.633
266.199	52.300	76.707	-0.200	-6.211	-6.211
268.399	51.800	75.973	-0.333	-10.352	-10.352
270.599	51.500	75.533	-0.200	-6.211	-6.211
272.799	52.000	76.267	0.333	10.352	10.352
274.999	53.000	77.733	0.667	20.704	20.704
277.199	54.200	79.493	0.800	24.845	24.845
279.399	55.500	81.400	0.867	26.915	26.915
281.599	56.000	82.133	0.333	10.352	10.352
283.799	55.300	81.107	-0.467	-14.493	-14.493
285.999	53.600	79.613	-1.133	-35.197	-35.197
288.199	51.500	75.533	-1.400	-43.478	-43.478
290.399	51.300	75.240	-0.133	-4.141	-4.141
292.599	50.100	73.480	-0.800	-24.845	-24.845
294.799	50.000	73.333	-0.067	-2.071	-2.071
296.999	49.500	72.600	-0.333	-10.352	-10.352
299.199	49.400	72.453	-0.067	-2.071	-2.071
301.399	48.400	70.987	-0.667	-20.704	-20.704
303.599	46.500	68.200	-1.267	-39.337	-39.337
305.799	44.000	64.533	-1.667	-51.760	-51.760
307.999	41.500	60.867	-1.667	-51.760	-51.760
310.198	38.200	56.027	-2.200	-68.323	-68.323
312.398	34.700	50.893	-2.333	-72.464	-72.464
314.598	31.900	46.787	-1.867	-57.971	-57.971
316.798	30.500	44.733	-0.933	-28.985	-28.985
318.998	29.000	42.533	-1.000	-31.056	-31.056
321.198	24.100	35.347	-3.267	-101.449	-101.449
323.398	19.700	28.893	-2.933	-91.098	-91.098
325.598	17.600	25.813	-1.400	-43.478	-43.478
327.798	13.100	19.213	-3.000	-93.168	-93.168

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME	VELOCITY		ACCELERATION	FORCE	TORQUE
(SEC)	(MPH)	(FPS)	(FT/SEC**2)	(LBS)	(FT*LBS)
329.998	8.000	11.733	-3.400	-105.590	-105.590
332.198	1.100	1.613	-4.600	-142.857	-142.857
334.398	0.0	0.0	-0.733	-22.774	-22.774
336.598	0.0	0.0	0.0	0.0	0.0
338.798	0.0	0.0	0.0	0.0	0.0
340.998	0.0	0.0	0.0	0.0	0.0
343.198	0.0	0.0	0.0	0.0	0.0
345.398	0.0	0.0	0.0	0.0	0.0
347.598	3.000	4.400	2.000	62.112	62.112
349.798	9.200	13.493	4.133	128.364	128.364
351.998	17.300	25.373	5.400	167.702	167.702
354.198	22.700	33.293	3.600	111.801	111.801
356.397	25.700	37.693	2.000	62.112	62.112
358.597	29.200	42.827	2.333	72.464	72.464
360.797	31.400	46.053	1.467	45.548	45.548
362.997	32.800	48.107	0.933	28.986	28.986
365.197	34.500	50.600	1.133	35.197	35.197
367.397	34.900	51.187	0.267	8.291	8.281
369.597	34.600	50.747	-0.200	-6.211	-6.211
371.797	35.900	52.653	0.867	26.915	26.915
373.997	36.000	52.800	0.067	2.070	2.070
376.197	36.000	52.800	0.0	0.0	0.0
378.397	36.200	53.093	0.133	4.141	4.141
380.597	36.500	53.533	0.200	6.211	6.211
382.797	35.300	51.773	-0.800	-24.845	-24.845
384.997	33.500	49.133	-1.200	-37.267	-37.267
387.197	28.300	41.507	-3.467	-107.660	-107.660
389.397	21.900	32.120	-4.267	-132.505	-132.505
391.597	15.700	23.027	-4.133	-128.364	-128.364
393.797	9.400	13.787	-4.200	-130.435	-130.435
395.997	2.100	3.080	-4.867	-151.139	-151.139
398.197	0.0	0.0	-1.400	-43.478	-43.478
400.396	0.0	0.0	0.0	0.0	0.0
402.596	1.600	2.347	1.067	33.126	33.126
404.796	8.500	12.467	4.600	142.857	142.857
406.996	15.300	23.173	4.867	151.139	151.139
409.196	22.400	33.587	4.733	146.998	146.998
411.396	26.400	38.720	2.333	72.464	72.464
413.596	29.600	43.413	2.133	66.253	66.253
415.796	30.000	44.000	0.267	8.282	8.282
417.996	29.300	42.973	-0.467	-14.493	-14.493
420.196	27.400	40.187	-1.267	-39.337	-39.337
422.396	20.400	29.920	-4.667	-144.928	-144.928
424.596	13.100	19.213	-4.867	-151.138	-151.138
426.796	5.900	8.653	-4.800	-149.068	-149.068
428.996	0.0	0.0	-3.933	-122.153	-122.153
431.196	0.0	0.0	0.0	0.0	0.0
433.396	0.0	0.0	0.0	0.0	0.0
435.596	0.0	0.0	0.0	0.0	0.0
437.796	0.0	0.0	0.0	0.0	0.0

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME (SEC)	VELOCITY (MPH)	VELOCITY (FPS)	ACCELERATION (FT/SEC**2)	FORCE (LBS)	TORQUE (FT-LBS)
439.996	0.0	0.0	0.0	0.0	0.0
442.196	0.0	0.0	0.0	0.0	0.0
444.396	0.0	0.0	0.0	0.0	0.0
446.595	0.0	0.0	0.0	0.0	0.0
448.795	5.900	8.653	3.933	122.153	122.153
450.995	13.200	19.360	4.867	151.139	151.139
453.195	20.500	30.067	4.867	151.139	151.139
455.395	27.000	39.600	4.333	134.575	134.575
457.595	30.500	44.733	2.333	72.464	72.464
459.795	33.000	48.400	1.667	51.760	51.760
461.995	35.100	51.480	1.400	43.478	43.478
464.195	36.100	52.947	0.667	20.704	20.704
466.395	36.100	52.947	0.0	0.0	0.0
468.595	35.800	52.507	-0.200	-6.211	-6.211
470.795	36.000	52.800	0.133	4.141	4.141
472.995	35.500	52.067	-0.333	-10.352	-10.352
475.195	35.100	51.480	-0.267	-8.282	-8.282
477.395	35.100	51.480	0.0	0.0	0.0
479.595	35.200	51.627	0.067	2.070	2.070
481.795	35.100	51.480	-0.067	-2.070	-2.070
483.995	35.500	52.067	0.267	8.282	8.282
486.195	35.000	51.333	-0.333	-10.352	-10.352
488.395	34.900	51.187	-0.067	-2.071	-2.071
490.594	34.500	50.600	-0.267	-8.281	-8.281
492.794	32.300	47.373	-1.467	-45.548	-45.548
494.994	28.000	41.067	-2.867	-89.027	-89.027
497.194	22.000	32.267	-4.000	-124.224	-124.224
499.394	15.200	22.293	-4.533	-140.787	-140.787
501.594	8.400	12.320	-4.533	-140.787	-140.787
503.794	1.600	2.347	-4.533	-140.787	-140.787
505.994	0.0	0.0	-1.067	-33.126	-33.126
508.194	0.0	0.0	0.0	0.0	0.0
510.394	0.800	1.173	0.533	16.563	16.563
512.594	4.700	6.893	2.600	80.745	80.745
514.794	8.100	11.880	2.267	70.393	70.393
516.994	10.500	15.400	1.600	49.689	49.689
519.194	14.400	21.120	2.600	80.745	80.745
521.394	18.200	26.693	2.533	78.675	78.675
523.594	20.600	30.213	1.600	49.689	49.689
525.794	22.800	33.440	1.467	45.549	45.549
527.994	24.500	35.933	1.133	35.197	35.197
530.194	25.000	36.667	0.333	10.352	10.352
532.394	25.000	36.667	0.0	0.0	0.0
534.594	25.000	36.667	0.0	0.0	0.0
536.793	25.800	37.840	0.533	16.563	16.563
538.993	25.600	37.547	-0.133	-4.141	-4.141
541.193	25.000	36.667	-0.400	-12.423	-12.423
543.393	24.800	36.373	-0.133	-4.141	-4.141
545.593	21.100	30.947	-2.467	-76.605	-76.605
547.793	13.900	20.387	-4.800	-149.068	-149.068

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME	VELOCITY		ACCELERATION	FORCE	TORQUE
(SEC)	(MPH)	(FPS)	(FT/SEC**2)	(LBS)	(FT*LBS)
549.993	6.600	9.680	-4.867	-151.139	-151.139
552.193	0.0	0.0	-4.400	-136.646	-136.646
554.393	0.0	0.0	0.0	0.0	0.0
556.593	0.0	0.0	0.0	0.0	0.0
558.793	0.0	0.0	0.0	0.0	0.0
560.993	0.0	0.0	0.0	0.0	0.0
563.193	0.0	0.0	0.0	0.0	0.0
565.393	0.0	0.0	0.0	0.0	0.0
567.593	0.0	0.0	0.0	0.0	0.0
569.793	5.900	8.653	3.933	122.153	122.153
571.993	13.000	19.067	4.733	146.998	146.998
574.193	16.200	23.760	2.133	66.253	66.253
576.393	17.000	24.933	0.533	16.563	16.563
578.593	17.600	25.813	0.400	12.422	12.422
580.792	17.600	25.813	0.0	0.0	0.0
582.992	16.900	24.787	-0.467	-14.493	-14.493
585.192	17.000	24.933	0.067	2.071	2.071
587.392	16.800	24.640	-0.133	-4.141	-4.141
589.592	16.500	24.200	-0.200	-6.211	-6.211
591.792	16.900	24.787	0.267	8.281	8.281
593.992	18.500	27.133	1.067	33.126	33.126
596.192	20.400	29.920	1.267	39.337	39.337
598.392	21.100	30.947	0.467	14.493	14.493
600.592	21.800	31.973	0.467	14.493	14.493
602.792	22.500	33.000	0.467	14.493	14.493
604.992	22.500	33.000	0.0	0.0	0.0
607.192	24.000	35.200	1.000	31.056	31.056
609.392	26.200	38.427	1.467	45.548	45.548
611.592	26.500	38.867	0.200	6.211	6.211
613.792	20.200	29.627	-4.200	-130.435	-130.435
615.992	12.900	18.920	-4.867	-151.139	-151.139
618.192	8.900	13.053	-2.667	-82.816	-82.816
620.392	0.0	0.0	-5.933	-184.265	-184.265
622.592	0.0	0.0	0.0	0.0	0.0
624.792	0.0	0.0	0.0	0.0	0.0
626.991	0.0	0.0	0.0	0.0	0.0
629.191	0.0	0.0	0.0	0.0	0.0
631.391	0.0	0.0	0.0	0.0	0.0
633.591	0.0	0.0	0.0	0.0	0.0
635.791	0.0	0.0	0.0	0.0	0.0
637.991	0.0	0.0	0.0	0.0	0.0
640.191	0.0	0.0	0.0	0.0	0.0
642.391	0.0	0.0	0.0	0.0	0.0
644.591	0.0	0.0	0.0	0.0	0.0
646.791	4.000	5.867	2.667	82.816	82.816
648.991	10.200	14.960	4.133	128.364	128.364
651.191	14.200	20.827	2.667	82.816	82.816
653.391	18.300	26.840	2.733	84.886	84.886
655.591	21.700	31.827	2.267	70.393	70.393
657.791	24.300	35.640	1.733	53.830	53.830

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME	VELOCITY		ACCELERATION	FORCE	TORQUE
(SEC)	(MPH)	(FPS)	(FT/SEC**2)	(LBS)	(FT*LBS)
659.991	25.600	37.547	0.867	26.915	26.915
662.191	26.100	38.280	0.333	10.352	10.352
664.391	26.300	38.573	0.133	4.141	4.141
666.591	26.500	38.867	0.133	4.141	4.141
668.791	25.600	37.547	-0.600	-18.633	-18.633
670.990	21.400	31.387	-2.800	-86.957	-86.957
673.190	16.000	23.467	-3.600	-111.801	-111.801
675.390	10.400	15.253	-3.733	-115.942	-115.942
677.590	4.400	6.453	-4.000	-124.224	-124.224
679.790	0.0	0.0	-2.933	-91.097	-91.097
681.990	0.0	0.0	0.0	0.0	0.0
684.190	0.0	0.0	0.0	0.0	0.0
686.390	0.0	0.0	0.0	0.0	0.0
688.590	0.0	0.0	0.0	0.0	0.0
690.790	0.0	0.0	0.0	0.0	0.0
692.990	0.0	0.0	0.0	0.0	0.0
695.190	3.500	5.133	2.333	72.464	72.464
697.390	7.600	11.147	2.733	84.886	84.886
699.590	12.600	18.480	3.333	103.519	103.519
701.790	16.000	23.467	2.267	70.394	70.394
703.990	16.500	24.200	0.333	10.352	10.352
706.190	18.400	26.987	1.267	39.337	39.337
708.390	20.700	30.360	1.533	47.619	47.619
710.590	22.500	33.000	1.200	37.267	37.267
712.790	22.600	33.147	0.067	2.070	2.070
714.990	23.500	34.467	0.600	18.633	18.633
717.189	21.400	31.387	-1.400	-43.478	-43.478
719.389	16.800	24.640	-3.067	-95.238	-95.238
721.589	10.200	14.960	-4.400	-136.646	-136.646
723.789	4.800	7.040	-3.600	-111.801	-111.801
725.989	2.100	3.080	-1.800	-55.901	-55.901
728.189	1.000	1.467	-0.733	-22.774	-22.774
730.389	7.700	11.293	4.467	138.716	138.716
732.589	13.400	19.653	3.800	118.012	118.012
734.789	17.600	25.813	2.800	86.957	86.957
736.989	21.500	31.533	2.600	80.745	80.745
739.189	24.700	36.227	2.133	66.253	66.253
741.389	25.700	39.160	1.333	41.408	41.408
743.589	27.700	40.627	0.667	20.704	20.704
745.789	28.500	41.800	0.533	16.563	16.563
747.989	28.300	41.507	-0.133	-4.141	-4.141
750.189	27.900	40.920	-0.267	-8.282	-8.282
752.389	26.300	38.573	-1.067	-33.125	-33.125
754.589	22.300	32.707	-2.667	-82.816	-82.816
756.789	17.000	24.933	-3.533	-109.731	-109.731
758.989	12.500	18.333	-3.000	-93.168	-93.168
761.188	5.600	8.213	-4.600	-142.857	-142.857
763.388	1.500	2.200	-2.733	-84.886	-84.886
765.588	0.200	0.293	-0.867	-26.915	-26.915
767.788	5.600	8.213	3.600	111.801	111.801

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME (SEC)	VELOCITY (MPH)	VELOCITY (FPS)	ACCELERATION (FT/SEC**2)	FORCE (LBS)	TORQUE (FT*LBS)
769.988	12.900	18.920	4.867	151.138	151.138
772.188	17.700	25.960	3.200	99.379	99.379
774.388	20.000	29.333	1.533	47.619	47.619
776.588	22.700	33.293	1.800	55.900	55.900
778.788	26.200	38.427	2.333	72.464	72.464
780.988	28.300	41.067	1.200	37.267	37.267
783.188	29.900	42.387	0.600	18.633	18.633
785.388	28.800	42.240	-0.067	-2.070	-2.070
787.588	28.400	41.653	-0.267	-8.282	-8.282
789.788	28.300	41.507	-0.067	-2.070	-2.070
791.988	27.600	40.480	-0.467	-14.493	-14.493
794.188	27.500	40.333	-0.067	-2.071	-2.071
796.388	27.500	40.333	0.0	0.0	0.0
798.588	27.500	40.333	0.0	0.0	0.0
800.788	28.400	41.653	0.600	18.633	18.633
802.988	31.000	45.467	1.733	53.830	53.830
805.187	33.000	48.400	1.333	41.409	41.409
807.387	33.700	49.427	0.467	14.493	14.493
809.587	34.200	50.160	0.333	10.352	10.352
811.787	34.000	49.867	-0.133	-4.141	-4.141
813.987	33.600	49.280	-0.267	-8.281	-8.281
816.187	32.900	48.253	-0.467	-14.493	-14.493
818.387	32.000	46.933	-0.600	-18.633	-18.633
820.587	31.500	46.200	-0.333	-10.352	-10.352
822.787	30.100	44.147	-0.933	-28.985	-28.985
824.987	29.900	43.853	-0.133	-4.141	-4.141
827.187	29.800	43.707	-0.067	-2.070	-2.070
829.387	29.500	43.267	-0.200	-6.211	-6.211
831.587	29.100	42.680	-0.267	-8.281	-8.281
833.787	27.800	40.773	-0.867	-26.915	-26.915
835.987	25.500	37.400	-1.533	-47.619	-47.619
838.187	21.700	31.827	-2.533	-78.675	-78.675
840.387	19.200	28.160	-1.667	-51.760	-51.760
842.587	20.600	30.213	0.933	28.986	28.986
844.787	21.900	32.120	0.867	26.915	26.915
846.987	23.200	34.027	0.867	26.915	26.915
849.187	25.200	36.960	1.333	41.409	41.409
851.386	25.600	37.547	0.267	8.282	8.282
853.586	26.900	39.453	0.867	26.915	26.915
855.786	27.700	40.627	0.533	16.563	16.563
857.986	28.800	42.240	0.733	22.774	22.774
860.186	29.000	42.533	0.133	4.141	4.141
862.386	28.600	41.947	-0.267	-8.281	-8.281
864.586	27.200	39.893	-0.933	-28.986	-28.986
866.786	25.200	36.960	-1.333	-41.408	-41.408
868.986	24.300	36.373	-0.267	-8.281	-8.281
871.186	25.500	37.400	0.467	14.493	14.493
873.386	25.500	38.867	0.667	20.704	20.704
875.586	27.700	40.627	0.800	24.845	24.845
877.786	28.900	42.387	0.800	24.845	24.845

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME	VELOCITY		ACCELERATION	FORCE	TORQUE
(SEC)	(MPH)	(FPS)	(FT/SEC**2)	(LBS)	(FT*LBS)
879.986	29.100	42.680	0.133	4.141	4.141
882.186	28.800	42.240	-0.200	-6.211	-6.211
884.386	28.100	41.213	-0.467	-14.493	-14.493
886.586	27.800	40.773	-0.200	-6.211	-6.211
888.786	26.700	39.160	-0.733	-22.774	-22.774
890.986	27.500	40.333	0.533	16.563	16.563
893.186	28.000	41.067	0.333	10.352	10.352
895.385	28.000	41.067	0.0	0.0	0.0
897.585	27.800	40.773	-0.133	-4.141	-4.141
899.785	27.000	39.600	-0.533	-16.563	-16.563
901.985	26.500	38.867	-0.333	-10.352	-10.352
904.185	26.500	38.867	0.0	0.0	0.0
906.385	26.200	38.427	-0.200	-6.211	-6.211
908.585	25.700	37.693	-0.333	-10.352	-10.352
910.785	25.800	37.840	0.067	2.070	2.070
912.985	25.500	37.400	-0.200	-6.211	-6.211
915.185	23.300	34.173	-1.467	-45.548	-45.548
917.385	21.600	31.680	-1.133	-35.197	-35.197
919.585	22.100	32.413	0.333	10.352	10.352
921.785	23.900	35.053	1.200	37.267	37.267
923.985	24.400	35.787	0.333	10.352	10.352
926.185	25.100	36.813	0.467	14.493	14.493
928.385	25.400	37.253	0.200	6.211	6.211
930.585	25.100	36.813	-0.200	-6.211	-6.211
932.785	25.000	36.667	-0.067	-2.071	-2.071
934.985	24.500	35.933	-0.333	-10.352	-10.352
937.185	24.300	35.640	-0.133	-4.141	-4.141
939.385	25.000	36.667	0.467	14.493	14.493
941.584	24.600	36.080	-0.267	-8.281	-8.281
943.784	24.400	35.787	-0.133	-4.141	-4.141
945.984	25.600	37.547	0.800	24.845	24.845
948.184	23.600	34.613	-1.333	-41.408	-41.408
950.384	18.300	27.573	-3.200	-99.379	-99.379
952.584	11.600	17.013	-4.800	-149.068	-149.068
954.784	4.400	6.453	-4.800	-149.068	-149.068
956.984	0.0	0.0	-2.933	-91.097	-91.097
959.184	0.400	0.587	0.267	8.282	8.282
961.384	6.400	9.387	4.000	124.224	124.224
963.584	13.900	20.387	5.000	155.279	155.279
965.784	18.400	26.987	3.000	93.168	93.168
967.984	21.100	30.947	1.800	55.901	55.901
970.184	23.300	34.173	1.467	45.549	45.549
972.384	26.800	39.307	2.333	72.464	72.464
974.584	28.300	41.507	1.000	31.056	31.056
976.784	28.500	41.800	0.133	4.141	4.141
978.984	27.700	40.627	-0.533	-16.563	-16.563
981.184	27.100	39.747	-0.400	-12.422	-12.422
983.384	26.300	38.573	-0.533	-16.563	-16.563
985.583	25.400	37.253	-0.600	-18.634	-18.634
987.783	22.400	32.853	-2.000	-62.112	-62.112

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME	VELOCITY		ACCELERATION	FORCE	TORQUE
(SEC)	(MPH)	(FPS)	(FT/SEC**2)	(LBS)	(FT*LBS)
989.983	21.500	31.533	-0.600	-18.633	-18.633
992.183	22.400	32.853	0.600	18.633	18.633
994.383	22.800	33.440	0.267	8.282	8.282
996.583	22.800	33.440	0.0	0.0	0.0
998.783	22.700	33.293	-0.067	-2.071	-2.071
1000.983	24.000	35.200	0.867	26.915	26.915
1003.183	24.900	36.520	0.600	18.633	18.633
1005.383	25.500	37.400	0.400	12.422	12.422
1007.583	25.200	36.960	-0.200	-6.211	-6.211
1009.783	23.800	34.907	-0.933	-28.985	-28.985
1011.983	22.900	33.587	-0.600	-18.634	-18.634
1014.183	21.900	32.120	-0.667	-20.704	-20.704
1016.383	19.300	28.307	-1.733	-53.830	-53.830
1018.583	12.200	17.893	-4.733	-146.998	-146.998
1020.783	5.000	7.333	-4.800	-149.068	-149.068
1022.983	0.0	0.0	-3.333	-103.520	-103.520
1025.183	0.0	0.0	0.0	0.0	0.0
1027.383	0.0	0.0	0.0	0.0	0.0
1029.583	0.0	0.0	0.0	0.0	0.0
1031.782	0.0	0.0	0.0	0.0	0.0
1033.982	0.0	0.0	0.0	0.0	0.0
1036.182	0.0	0.0	0.0	0.0	0.0
1038.382	0.0	0.0	0.0	0.0	0.0
1040.582	0.0	0.0	0.0	0.0	0.0
1042.782	0.0	0.0	0.0	0.0	0.0
1044.982	0.0	0.0	0.0	0.0	0.0
1047.182	0.0	0.0	0.0	0.0	0.0
1049.382	0.0	0.0	0.0	0.0	0.0
1051.582	0.0	0.0	0.0	0.0	0.0
1053.782	3.400	4.987	2.267	70.393	70.393
1055.982	10.600	15.547	4.800	149.068	149.068
1058.182	17.100	25.080	4.333	134.575	134.575
1060.382	20.700	30.360	2.400	74.534	74.534
1062.582	23.600	34.613	1.933	60.042	60.042
1064.782	25.400	37.253	1.200	37.267	37.267
1066.982	26.800	39.307	0.933	28.986	28.986
1069.182	28.000	41.067	0.800	24.845	24.845
1071.382	27.800	40.773	-0.133	-4.141	-4.141
1073.582	27.000	39.600	-0.533	-16.563	-16.563
1075.781	24.900	36.520	-1.400	-43.478	-43.478
1077.981	21.500	31.533	-2.267	-70.393	-70.393
1080.181	17.400	25.520	-2.733	-84.886	-84.886
1082.381	11.800	17.307	-3.733	-115.942	-115.942
1084.581	10.200	14.960	-1.067	-33.126	-33.126
1086.781	9.200	13.493	-0.667	-20.704	-20.704
1088.981	8.600	12.613	-0.400	-12.422	-12.422
1091.181	8.800	13.053	0.200	6.211	6.211
1093.381	8.400	12.320	-0.333	-10.352	-10.352
1095.581	5.800	8.507	-1.733	-53.830	-53.830
1097.781	2.900	4.253	-1.933	-60.041	-60.041

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME	VELOCITY		ACCELERATION	FORCE	TORQUE
(SEC)	(MPH)	(FPS)	(FT/SEC**2)	(LBS)	(FT*LBS)
1099.981	0.0	0.0	-1.933	-60.041	-60.041
1102.181	0.700	1.027	0.467	14.493	14.493
1104.381	4.900	7.187	2.800	86.956	86.956
1106.581	11.700	17.160	4.533	140.787	140.787
1108.781	14.400	21.120	1.800	55.900	55.900
1110.981	18.100	26.547	2.467	76.605	76.605
1113.181	21.000	30.800	1.933	60.041	60.041
1115.381	21.300	31.240	0.200	6.211	6.211
1117.581	22.200	32.560	0.600	18.633	18.633
1119.781	23.600	34.613	0.933	28.986	28.986
1121.980	25.000	36.667	0.933	28.985	28.985
1124.180	24.800	36.373	-0.133	-4.141	-4.141
1126.380	25.600	37.547	0.533	16.563	16.563
1128.580	26.200	38.427	0.400	12.422	12.422
1130.780	26.800	39.307	0.400	12.423	12.423
1132.980	27.000	39.600	0.133	4.141	4.141
1135.180	26.900	39.453	-0.067	-2.070	-2.070
1137.380	26.700	39.160	-0.133	-4.141	-4.141
1139.580	26.200	38.427	-0.333	-10.352	-10.352
1141.780	24.600	36.080	-1.067	-33.126	-33.126
1143.980	21.500	31.533	-2.067	-64.182	-64.182
1146.180	17.200	25.227	-2.867	-89.027	-89.027
1148.380	12.700	18.627	-3.000	-93.168	-93.168
1150.580	5.400	7.920	-4.867	-151.138	-151.138
1152.780	0.200	0.293	-3.467	-107.660	-107.660
1154.980	0.0	0.0	-0.133	-4.141	-4.141
1157.180	0.0	0.0	0.0	0.0	0.0
1159.380	0.0	0.0	0.0	0.0	0.0
1161.580	0.0	0.0	0.0	0.0	0.0
1163.780	0.0	0.0	0.0	0.0	0.0
1165.979	0.0	0.0	0.0	0.0	0.0
1168.179	0.400	0.587	0.267	8.282	8.282
1170.379	6.700	9.827	4.200	130.435	130.435
1172.579	14.000	20.533	4.867	151.139	151.139
1174.779	20.600	30.213	4.400	136.646	136.646
1176.979	23.500	34.467	1.933	60.041	60.041
1179.179	22.000	32.267	-1.000	-31.056	-31.056
1181.379	15.400	22.587	-4.400	-136.646	-136.646
1183.579	8.100	11.880	-4.867	-151.139	-151.139
1185.779	0.900	1.320	-4.800	-149.068	-149.068
1187.979	0.0	0.0	-0.600	-18.634	-18.634
1190.179	0.0	0.0	0.0	0.0	0.0
1192.379	0.0	0.0	0.0	0.0	0.0
1194.579	0.0	0.0	0.0	0.0	0.0
1196.779	0.200	0.293	0.133	4.141	4.141
1198.979	3.500	5.133	2.200	68.323	68.323
1201.179	10.200	14.960	4.467	138.716	138.716
1203.379	12.900	18.920	1.800	55.900	55.900
1205.579	12.700	18.627	-0.133	-4.141	-4.141
1207.779	13.100	19.213	0.267	8.282	8.282

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS — 625 PTS

TIME	VELOCITY		ACCELERATION	FORCE	TORQUE
(SEC)	(MPH)	(FPS)	(FT/SEC**2)	(LBS)	(FT*LBS)
1209.979	15.500	22.733	1.600	49.689	49.689
1212.178	18.800	27.573	2.200	68.323	68.323
1214.378	21.200	31.093	1.600	49.689	49.689
1216.578	21.800	31.973	0.400	12.423	12.423
1218.778	21.300	31.240	-0.333	-10.352	-10.352
1220.978	21.800	31.973	0.333	10.352	10.352
1223.178	21.900	32.120	0.067	2.070	2.070
1225.378	21.500	31.533	-0.267	-8.282	-8.282
1227.578	20.600	30.213	-0.600	-18.633	-18.633
1229.778	19.300	28.307	-0.867	-26.915	-26.915
1231.978	19.800	29.040	0.333	10.352	10.352
1234.178	19.100	28.013	-0.467	-14.493	-14.493
1236.378	14.500	21.267	-3.067	-95.238	-95.238
1238.578	8.800	12.907	-3.800	-118.012	-118.012
1240.778	4.400	6.453	-2.933	-91.097	-91.097
1242.978	0.700	1.027	-2.467	-76.605	-76.605
1245.178	0.0	0.0	-0.467	-14.493	-14.493
1247.378	0.0	0.0	0.0	0.0	0.0
1249.578	0.0	0.0	0.0	0.0	0.0
1251.778	0.800	1.173	0.533	16.563	16.563
1253.978	1.000	1.467	0.133	4.141	4.141
1256.177	1.100	1.613	0.067	2.070	2.070
1258.377	3.400	4.987	1.533	47.619	47.619
1260.577	5.400	7.920	1.333	41.408	41.408
1262.777	9.600	14.080	2.800	86.956	86.956
1264.977	9.500	13.933	-0.067	-2.070	-2.070
1267.177	7.800	11.440	-1.133	-35.197	-35.197
1269.377	12.200	17.893	2.933	91.097	91.097
1271.577	18.500	27.133	4.200	130.435	130.435
1273.777	21.600	31.680	2.067	64.182	64.182
1275.977	23.000	33.733	0.933	28.985	28.985
1278.177	24.200	35.493	0.800	24.845	24.845
1280.377	24.300	35.640	0.067	2.070	2.070
1282.577	23.500	34.467	-0.533	-16.563	-16.563
1284.777	23.500	34.467	0.0	0.0	0.0
1286.977	23.500	34.467	0.0	0.0	0.0
1289.177	24.200	35.493	0.467	14.493	14.493
1291.377	24.800	36.373	0.400	12.422	12.422
1293.577	25.500	37.400	0.467	14.493	14.493
1295.777	25.900	37.987	0.267	8.281	8.281
1297.977	27.000	39.600	0.733	22.774	22.774
1300.177	28.400	41.653	0.933	28.985	28.985
1302.376	29.100	42.680	0.467	14.493	14.493
1304.576	26.000	38.133	-2.067	-64.182	-64.182
1306.776	18.800	27.573	-4.800	-149.068	-149.068
1308.976	11.500	16.867	-4.867	-151.139	-151.139
1311.176	4.200	6.160	-4.867	-151.139	-151.139
1313.376	0.0	0.0	-2.800	-86.956	-86.956
1315.576	0.0	0.0	0.0	0.0	0.0
1317.776	0.0	0.0	0.0	0.0	0.0

TABLE A-1 (Cont.)

EPA URBAN LA-4 CYCLE 2.2 SEC INTERVALS - 625 PTS

TIME (SEC)	VELOCITY (MPH)	VELOCITY (FPS)	ACCELERATION (FT/SEC**2)	FORCE (LBS)	TORQUE (FT*LBS)
1319.976	0.0	0.0	0.0	0.0	0.0
1322.176	0.0	0.0	0.0	0.0	0.0
1324.376	0.0	0.0	0.0	0.0	0.0
1326.576	0.0	0.0	0.0	0.0	0.0
1328.776	0.0	0.0	0.0	0.0	0.0
1330.976	0.0	0.0	0.0	0.0	0.0
1333.176	0.0	0.0	0.0	0.0	0.0
1335.376	0.0	0.0	0.0	0.0	0.0
1337.576	0.900	1.320	0.600	18.634	18.634
1339.776	7.400	10.853	4.333	134.576	134.576
1341.976	13.200	19.360	3.867	120.083	120.083
1344.176	15.400	22.587	1.467	45.549	45.549
1346.375	19.800	29.040	2.933	91.097	91.097
1348.575	21.700	31.827	1.267	39.337	39.337
1350.775	22.300	32.707	0.400	12.422	12.422
1352.975	21.600	31.680	-0.467	-14.493	-14.493
1355.175	20.400	29.920	-0.800	-24.845	-24.845
1357.375	19.200	28.160	-0.800	-24.845	-24.845
1359.575	16.900	24.787	-1.533	-47.619	-47.619
1361.775	14.300	20.973	-1.733	-53.830	-53.830
1363.975	8.000	11.733	-4.200	-130.434	-130.434
1366.175	2.000	2.933	-4.000	-124.224	-124.224
1368.375	0.0	0.0	-1.333	-41.408	-41.408
1370.575	0.0	0.0	0.0	0.0	0.0
1372.775	0.0	0.0	0.0	0.0	0.0
1374.975	0.0	0.0	0.0	0.0	0.0
1377.175	0.0	0.0	0.0	0.0	0.0
1379.375	0.0	0.0	0.0	0.0	0.0
1381.575	0.0	0.0	0.0	0.0	0.0
1383.775	0.0	0.0	0.0	0.0	0.0

END OF DATA

TABLE A-2. EPA HIGHWAY FUEL ECONOMY CYCLE

TABLE A-2

WEIGHT = 1000.00LBS
WHEEL RADIUS = 1.00 FT

EPA HIGHWAY FUEL ECONOMY CYCLE (383 PTS)

TIME (SEC)	VELOCITY (MPH)	VELOCITY (FPS)	ACELERATION (FT/SEC**2)	FORCE (LBS)	TORQUE (FT*LBS)
0.0	0.0	0.0	0.0	0.0	0.0
2.000	0.0	0.0	0.0	0.0	0.0
4.000	4.900	7.187	3.593	111.594	111.594
6.000	11.300	16.573	4.693	145.755	145.755
8.000	17.300	25.373	4.400	136.646	136.646
10.000	21.800	31.973	3.300	102.485	102.485
12.000	25.800	37.840	2.933	91.097	91.097
14.000	28.000	41.067	1.613	50.104	50.104
16.000	30.000	44.000	1.467	45.549	45.549
18.000	31.500	46.200	1.100	34.161	34.161
20.000	32.900	48.253	1.027	31.884	31.884
22.000	34.100	50.013	0.880	27.330	27.330
24.000	34.900	51.187	0.587	18.219	18.219
26.000	35.700	52.360	0.587	18.220	18.220
28.000	35.800	52.507	0.073	2.278	2.278
30.000	34.900	51.187	-0.660	-20.497	-20.497
32.000	34.600	50.747	-0.220	-6.832	-6.832
34.000	35.100	51.480	0.367	11.387	11.387
36.000	36.100	52.947	0.733	22.774	22.774
38.000	36.500	53.533	0.293	9.110	9.110
40.000	36.900	54.120	0.293	9.110	9.110
42.000	37.000	54.267	0.073	2.278	2.278
44.000	37.000	54.267	0.0	0.0	0.0
46.000	37.000	54.267	0.0	0.0	0.0
48.000	37.300	54.707	0.220	6.832	6.832
50.000	38.600	56.613	0.953	29.607	29.607
52.000	40.000	58.667	1.027	31.884	31.884
54.000	41.400	60.720	1.027	31.884	31.884
56.000	42.900	62.920	1.100	34.161	34.161
58.000	44.000	64.533	0.807	25.052	25.052
60.000	44.500	65.267	0.367	11.387	11.387
62.000	44.900	65.853	0.293	9.110	9.110
64.000	45.100	66.147	0.147	4.555	4.555
66.000	45.700	67.027	0.440	13.664	13.664
68.000	46.300	67.907	0.440	13.665	13.665
70.000	46.800	68.640	0.367	11.387	11.387
72.000	47.000	68.933	0.147	4.555	4.555
74.000	47.200	69.227	0.147	4.555	4.555
76.000	47.200	69.227	0.0	0.0	0.0
78.000	47.000	68.933	-0.147	-4.555	-4.555
80.000	46.900	68.787	-0.073	-2.277	-2.277
82.000	47.000	68.933	0.073	2.277	2.277
84.000	47.100	69.080	0.073	2.278	2.278
86.000	47.100	69.080	0.0	0.0	0.0
88.000	46.900	68.787	-0.147	-4.555	-4.555
90.000	46.300	67.907	-0.440	-13.664	-13.664
92.000	46.300	67.907	0.0	0.0	0.0
94.000	46.900	68.787	0.440	13.664	13.664
96.000	47.400	69.520	0.367	11.387	11.387
98.000	48.000	70.400	0.440	13.665	13.665

TABLE A-2 (Cont.)

EPA HIGHWAY FUEL ECONOMY CYCLE (383 PTS)

TIME	VELOCITY		ACELERATION	FORCE	TORQUE
(SEC)	(MPH)	(FPS)	(FT/SEC**2)	(LBS)	(FT*LBS)
100.000	48.500	71.133	0.367	11.387	11.387
102.000	49.100	72.013	0.440	13.665	13.665
104.000	49.100	72.013	0.0	0.0	0.0
106.000	49.000	71.867	-0.073	-2.277	-2.277
108.000	49.100	72.013	0.073	2.277	2.277
110.000	49.300	72.307	0.147	4.555	4.555
112.000	49.500	72.600	0.147	4.555	4.555
114.000	49.500	72.600	0.0	0.0	0.0
116.000	49.100	72.013	-0.293	-9.110	-9.110
118.000	48.600	71.280	-0.367	-11.387	-11.387
120.000	48.100	70.547	-0.367	-11.387	-11.387
122.000	47.400	69.520	-0.513	-15.942	-15.942
124.000	47.500	69.667	0.073	2.278	2.278
126.000	47.900	70.253	0.293	9.110	9.110
128.000	47.900	70.253	0.0	0.0	0.0
130.000	47.900	70.253	0.0	0.0	0.0
132.000	48.000	70.400	0.073	2.278	2.278
134.000	47.900	70.253	-0.073	-2.278	-2.278
136.000	46.000	67.467	-1.393	-43.271	-43.271
138.000	41.200	60.427	-3.520	-109.317	-109.317
140.000	39.200	57.493	-1.467	-45.549	-45.549
142.000	39.000	57.200	-0.147	-4.555	-4.555
144.000	39.500	57.933	0.367	11.387	11.387
146.000	41.000	60.133	1.100	34.161	34.161
148.000	43.100	63.213	1.540	47.826	47.826
150.000	44.100	64.680	0.733	22.774	22.774
152.000	44.400	65.120	0.220	6.832	6.832
154.000	44.700	65.560	0.220	6.832	6.832
156.000	45.200	66.293	0.367	11.387	11.387
158.000	45.900	67.320	0.513	15.942	15.942
160.000	46.800	68.640	0.660	20.497	20.497
162.000	47.000	68.933	0.147	4.555	4.555
164.000	47.600	69.813	0.440	13.665	13.665
166.000	48.000	70.400	0.293	9.110	9.110
168.000	47.900	70.253	-0.073	-2.278	-2.278
170.000	47.300	69.373	-0.440	-13.664	-13.664
172.000	46.200	67.760	-0.807	-25.052	-25.052
174.000	45.700	67.027	-0.367	-11.387	-11.387
176.000	45.400	66.587	-0.220	-6.833	-6.833
178.000	45.000	66.000	-0.293	-9.110	-9.110
180.000	43.100	63.213	-1.393	-43.271	-43.271
182.000	41.500	60.867	-1.173	-36.439	-36.439
184.000	42.100	61.747	0.440	13.665	13.665
186.000	43.500	63.800	1.027	31.884	31.884
188.000	43.600	63.947	0.073	2.278	2.278
190.000	43.000	63.067	-0.440	-13.665	-13.665
192.000	43.400	63.653	0.293	9.110	9.110
194.000	44.300	64.973	0.660	20.497	20.497
196.000	44.900	65.853	0.440	13.664	13.664
198.000	44.400	65.120	-0.367	-11.387	-11.387

TABLE A-2 (Cont.)

EPA HIGHWAY FUEL ECONOMY CYCLE (383 PTS)

TIME (SEC)	VELOCITY (MPH)	VELOCITY (FPS)	ACELERATION (FT/SEC**2)	FORCE (LBS)	TORQUE (FT*LBS)
200.000	43.400	63.653	-0.733	-22.774	-22.774
202.000	43.200	63.360	-0.147	-4.555	-4.555
204.000	43.000	63.067	-0.147	-4.555	-4.555
206.000	43.100	63.213	0.073	2.278	2.278
208.000	43.900	64.387	0.587	18.219	18.219
210.000	43.500	63.800	-0.293	-9.110	-9.110
212.000	41.500	60.867	-1.467	-45.549	-45.549
214.000	40.000	58.667	-1.100	-34.161	-34.161
216.000	40.300	59.107	0.220	6.832	6.832
218.000	42.000	61.600	1.247	38.716	38.716
220.000	43.100	63.213	0.807	25.052	25.052
222.000	43.400	63.653	0.220	6.832	6.832
224.000	44.300	64.973	0.660	20.497	20.497
226.000	45.100	66.147	0.587	18.220	18.220
228.000	45.800	67.173	0.513	15.942	15.942
230.000	46.900	68.787	0.807	25.052	25.052
232.000	47.400	69.520	0.367	11.387	11.387
234.000	47.300	69.373	-0.073	-2.277	-2.277
236.000	47.200	69.227	-0.073	-2.277	-2.277
238.000	47.100	69.080	-0.073	-2.277	-2.277
240.000	47.000	68.933	-0.073	-2.278	-2.278
242.000	46.800	68.640	-0.147	-4.555	-4.555
244.000	47.000	68.933	0.147	4.555	4.555
246.000	47.500	69.667	0.367	11.387	11.387
248.000	48.000	70.400	0.367	11.387	11.387
250.000	48.000	70.400	0.0	0.0	0.0
252.000	48.000	70.400	0.0	0.0	0.0
254.000	48.200	70.693	0.147	4.555	4.555
256.000	48.100	70.547	-0.073	-2.277	-2.277
258.000	48.900	71.720	0.587	18.219	18.219
260.000	49.100	72.013	0.147	4.555	4.555
262.000	49.100	72.013	0.0	0.0	0.0
264.000	49.000	71.867	-0.073	-2.277	-2.277
266.000	48.200	70.693	-0.587	-18.220	-18.220
268.000	47.500	69.667	-0.513	-15.942	-15.942
270.000	46.700	68.493	-0.587	-18.220	-18.220
272.000	46.000	67.467	-0.513	-15.942	-15.942
274.000	45.600	66.880	-0.293	-9.110	-9.110
276.000	45.200	66.293	-0.293	-9.110	-9.110
278.000	44.700	65.560	-0.367	-11.387	-11.387
280.000	44.200	64.827	-0.367	-11.387	-11.387
282.000	42.800	62.773	-1.027	-31.884	-31.884
284.000	40.100	58.813	-1.980	-61.491	-61.491
286.000	37.500	55.000	-1.907	-59.214	-59.214
288.000	34.700	50.893	-2.053	-63.768	-63.768
290.000	33.300	48.840	-1.027	-31.884	-31.884
292.000	31.700	46.493	-1.173	-36.439	-36.439
294.000	29.600	43.413	-1.540	-47.826	-47.826
296.000	28.400	41.653	-0.880	-27.329	-27.329
298.000	29.500	43.267	0.807	25.052	25.052

TABLE A-2 (Cont.)

EPA HIGHWAY FUEL ECONOMY CYCLE (383 PTS)

TIME (SEC)	VELOCITY (MPH)	VELOCITY (FPS)	ACELERATION (FT/SEC**2)	FORCE (LBS)	TORQUE (FT*LBS)
300.000	33.400	48.987	2.860	88.820	88.820
302.000	37.500	55.000	3.007	93.375	93.375
304.000	40.200	58.960	1.980	61.491	61.491
306.000	41.800	61.307	1.173	36.439	36.439
308.000	42.800	62.773	0.733	22.774	22.774
310.000	43.800	64.240	0.733	22.774	22.774
312.000	44.700	65.560	0.660	20.497	20.497
314.000	45.200	66.293	0.367	11.387	11.387
316.000	45.500	66.733	0.220	6.832	6.832
318.000	46.000	67.467	0.367	11.387	11.387
320.000	46.500	68.200	0.367	11.387	11.387
322.000	47.100	69.080	0.440	13.665	13.665
324.000	48.300	70.840	0.880	27.329	27.329
326.000	49.700	72.893	1.027	31.884	31.884
328.000	51.000	74.800	0.953	29.607	29.607
330.000	52.400	76.853	1.027	31.884	31.884
332.000	53.800	78.907	1.027	31.884	31.884
334.000	55.200	80.960	1.027	31.884	31.884
336.000	56.400	82.720	0.880	27.329	27.329
338.000	57.000	83.600	0.440	13.665	13.665
340.000	57.300	84.040	0.220	6.833	6.833
342.000	57.800	84.773	0.367	11.387	11.387
344.000	58.100	85.213	0.220	6.832	6.832
346.000	58.700	86.093	0.440	13.664	13.664
348.000	58.900	86.387	0.147	4.555	4.555
350.000	59.000	86.533	0.073	2.277	2.277
352.000	58.800	86.240	-0.147	-4.555	-4.555
354.000	58.400	85.653	-0.293	-9.110	-9.110
356.000	58.100	85.213	-0.220	-6.832	-6.832
358.000	57.900	84.920	-0.147	-4.555	-4.555
360.000	57.400	84.187	-0.367	-11.387	-11.387
362.000	57.100	83.747	-0.220	-6.832	-6.832
364.000	57.000	83.600	-0.073	-2.278	-2.278
366.000	56.900	83.453	-0.073	-2.277	-2.277
368.000	57.000	83.600	0.073	2.277	2.277
370.000	57.000	83.600	0.0	0.0	0.0
372.000	57.000	83.600	0.0	0.0	0.0
374.000	57.000	83.600	0.0	0.0	0.0
376.000	57.000	83.600	0.0	0.0	0.0
378.000	56.800	83.307	-0.147	-4.555	-4.555
380.000	56.200	82.427	-0.440	-13.665	-13.665
382.000	56.000	82.133	-0.147	-4.555	-4.555
384.000	56.100	82.280	0.073	2.278	2.278
386.000	56.700	83.160	0.440	13.664	13.664
388.000	57.100	83.747	0.293	9.110	9.110
390.000	57.400	84.187	0.220	6.832	6.832
392.000	57.200	83.893	-0.147	-4.555	-4.555
394.000	56.900	83.453	-0.220	-6.832	-6.832
396.000	56.300	82.573	-0.440	-13.664	-13.664
398.000	56.400	82.720	0.073	2.277	2.277

TABLE A-2 (Cont.)

EPA HIGHWAY FUEL ECONOMY CYCLE (383 PTS)

TIME (SEC)	VELOCITY (MPH)	(FPS)	ACELERATION (FT/SEC**2)	FORCE (LBS)	TORQUE (FT*LBS)
400.000	57.100	83.747	0.513	15.942	15.942
402.000	57.800	84.773	0.513	15.942	15.942
404.000	58.000	85.067	0.147	4.555	4.555
406.000	58.000	85.067	0.0	0.0	0.0
408.000	58.000	85.067	0.0	0.0	0.0
410.000	57.800	84.773	-0.147	-4.555	-4.555
412.000	57.700	84.627	-0.073	-2.277	-2.277
414.000	57.900	84.920	0.147	4.555	4.555
416.000	58.100	85.213	0.147	4.555	4.555
418.000	58.900	86.387	0.587	18.219	18.219
420.000	59.400	87.120	0.367	11.387	11.387
422.000	59.900	87.853	0.367	11.387	11.387
424.000	59.800	87.707	-0.073	-2.277	-2.277
426.000	59.400	87.120	-0.293	-9.110	-9.110
428.000	59.100	86.680	-0.220	-6.832	-6.832
430.000	58.900	86.387	-0.147	-4.555	-4.555
432.000	58.600	85.947	-0.220	-6.832	-6.832
434.000	58.400	85.653	-0.147	-4.555	-4.555
436.000	58.300	85.507	-0.073	-2.277	-2.277
438.000	58.100	85.213	-0.147	-4.555	-4.555
440.000	57.900	84.920	-0.147	-4.555	-4.555
442.000	57.900	84.920	0.0	0.0	0.0
444.000	57.900	84.920	0.0	0.0	0.0
446.000	58.100	85.213	0.147	4.555	4.555
448.000	58.200	85.360	0.073	2.277	2.277
450.000	58.200	85.360	0.0	0.0	0.0
452.000	58.000	85.067	-0.147	-4.555	-4.555
454.000	58.000	85.067	0.0	0.0	0.0
456.000	58.000	85.067	0.0	0.0	0.0
458.000	57.900	84.920	-0.073	-2.278	-2.278
460.000	58.000	85.067	0.073	2.278	2.278
462.000	58.100	85.213	0.073	2.277	2.277
464.000	58.300	85.507	0.147	4.555	4.555
466.000	58.300	85.507	0.0	0.0	0.0
468.000	58.100	85.213	-0.147	-4.555	-4.555
470.000	57.800	84.773	-0.220	-6.832	-6.832
472.000	57.100	83.747	-0.513	-15.942	-15.942
474.000	56.600	83.013	-0.367	-11.387	-11.387
476.000	56.000	82.133	-0.440	-13.665	-13.665
478.000	55.500	81.400	-0.367	-11.387	-11.387
480.000	55.100	80.813	-0.293	-9.110	-9.110
482.000	54.900	80.520	-0.147	-4.555	-4.555
484.000	54.900	80.520	0.0	0.0	0.0
486.000	54.900	80.520	0.0	0.0	0.0
488.000	55.000	80.667	0.073	2.278	2.278
490.000	55.000	80.667	0.0	0.0	0.0
492.000	55.000	80.667	0.0	0.0	0.0
494.000	55.100	80.813	0.073	2.277	2.277
496.000	55.000	80.667	-0.073	-2.277	-2.277
498.000	54.900	80.520	-0.073	-2.278	-2.278

TABLE A-2 (Cont.)

EPA HIGHWAY FUEL ECONOMY CYCLE (383 PTS)

TIME (SEC)	VELOCITY (MPH)	VELOCITY (FPS)	ACELERATION (FT/SEC**2)	FORCE (LBS)	TORQUE (FT*LBS)
500.000	54.700	80.227	-0.147	-4.555	-4.555
502.000	54.400	79.787	-0.220	-6.832	-6.832
504.000	54.300	79.640	-0.073	-2.277	-2.277
506.000	54.100	79.347	-0.147	-4.555	-4.555
508.000	54.100	79.347	0.0	0.0	0.0
510.000	54.000	79.200	-0.073	-2.278	-2.278
512.000	54.000	79.200	0.0	0.0	0.0
514.000	54.000	79.200	0.0	0.0	0.0
516.000	54.000	79.200	0.0	0.0	0.0
518.000	54.200	79.493	0.147	4.555	4.555
520.000	54.800	80.373	0.440	13.665	13.665
522.000	55.000	80.667	0.147	4.555	4.555
524.000	55.200	80.960	0.147	4.555	4.555
526.000	55.300	81.107	0.073	2.278	2.278
528.000	55.500	81.400	0.147	4.555	4.555
530.000	55.700	81.693	0.147	4.555	4.555
532.000	55.900	81.987	0.147	4.555	4.555
534.000	56.000	82.133	0.073	2.278	2.278
536.000	56.000	82.133	0.0	0.0	0.0
538.000	56.000	82.133	0.0	0.0	0.0
540.000	56.000	82.133	0.0	0.0	0.0
542.000	56.000	82.133	0.0	0.0	0.0
544.000	56.000	82.133	0.0	0.0	0.0
546.000	56.000	82.133	0.0	0.0	0.0
548.000	55.900	81.987	-0.073	-2.278	-2.278
550.000	55.800	81.840	-0.073	-2.277	-2.277
552.000	55.400	81.253	-0.293	-9.110	-9.110
554.000	55.100	80.813	-0.220	-6.832	-6.832
556.000	54.900	80.520	-0.147	-4.555	-4.555
558.000	54.400	79.787	-0.367	-11.387	-11.387
560.000	54.100	79.347	-0.220	-6.832	-6.832
562.000	53.400	78.320	-0.513	-15.942	-15.942
564.000	53.100	77.880	-0.220	-6.832	-6.832
566.000	52.600	77.147	-0.367	-11.387	-11.387
568.000	52.200	76.560	-0.293	-9.110	-9.110
570.000	52.000	76.267	-0.147	-4.555	-4.555
572.000	52.000	76.267	0.0	0.0	0.0
574.000	52.100	76.413	0.073	2.278	2.278
576.000	52.000	76.267	-0.073	-2.278	-2.278
578.000	51.600	75.680	-0.293	-9.110	-9.110
580.000	51.100	74.947	-0.367	-11.387	-11.387
582.000	50.300	73.773	-0.587	-18.220	-18.220
584.000	49.300	72.307	-0.733	-22.774	-22.774
586.000	48.200	70.693	-0.807	-25.052	-25.052
588.000	48.300	70.400	-0.147	-4.555	-4.555
590.000	48.100	70.547	0.073	2.277	2.277
592.000	48.900	71.720	0.587	18.219	18.219
594.000	49.100	72.013	0.147	4.555	4.555
596.000	49.000	71.867	-0.073	-2.277	-2.277
598.000	48.900	71.720	-0.073	-2.278	-2.278

TABLE A-2 (Cont.)

EPA HIGHWAY FUEL ECONOMY CYCLE (383 PTS)

TIME (SEC)	VELOCITY (MPH)	VELOCITY (FPS)	ACELERATION (FT/SEC**2)	FORCE (LBS)	TORQUE (FT*LBS)
600.000	48.300	70.840	-0.440	-13.664	-13.664
602.000	47.900	70.253	-0.293	-9.110	-9.110
604.000	47.700	69.960	-0.147	-4.555	-4.555
606.000	48.300	70.840	0.440	13.665	13.665
608.000	49.100	72.013	0.587	18.219	18.219
610.000	48.900	71.720	-0.147	-4.555	-4.555
612.000	47.100	69.080	-1.320	-40.993	-40.993
614.000	46.100	67.613	-0.733	-22.774	-22.774
616.000	46.200	67.760	0.073	2.277	2.277
618.000	47.800	70.107	1.173	36.439	36.439
620.000	49.700	72.893	1.393	43.271	43.271
622.000	51.500	75.533	1.320	40.994	40.994
624.000	52.700	77.293	0.880	27.329	27.329
626.000	53.600	78.613	0.660	20.497	20.497
628.000	54.100	79.347	0.367	11.387	11.387
630.000	54.700	80.227	0.440	13.664	13.664
632.000	55.400	81.253	0.513	15.942	15.942
634.000	55.000	80.667	-0.293	-9.110	-9.110
636.000	53.600	78.613	-1.027	-31.884	-31.884
638.000	50.200	73.627	-2.493	-77.433	-77.433
640.000	46.500	68.200	-2.713	-84.265	-84.265
642.000	46.000	67.467	-0.367	-11.387	-11.387
644.000	46.300	67.907	0.220	6.832	6.832
646.000	47.500	69.667	0.880	27.329	27.329
648.000	48.800	71.573	0.953	29.607	29.607
650.000	50.200	73.627	1.027	31.884	31.884
652.000	51.100	74.947	0.660	20.497	20.497
654.000	52.200	76.560	0.807	25.052	25.052
656.000	52.100	76.413	-0.073	-2.277	-2.277
658.000	51.100	74.947	-0.733	-22.774	-22.774
660.000	51.000	74.800	-0.073	-2.277	-2.277
662.000	51.400	75.387	0.293	9.110	9.110
664.000	52.000	76.267	0.440	13.665	13.665
666.000	52.500	77.000	0.367	11.387	11.387
668.000	52.700	77.293	0.147	4.555	4.555
670.000	52.300	76.707	-0.293	-9.110	-9.110
672.000	52.400	76.853	0.073	2.277	2.277
674.000	52.700	77.293	0.220	6.833	6.833
676.000	52.400	76.853	-0.220	-6.833	-6.833
678.000	51.700	75.827	-0.513	-15.942	-15.942
680.000	50.500	74.067	-0.880	-27.329	-27.329
682.000	49.800	73.040	-0.513	-15.942	-15.942
684.000	49.600	72.747	-0.147	-4.555	-4.555
686.000	49.500	72.600	-0.073	-2.277	-2.277
688.000	50.000	73.333	0.367	11.387	11.387
690.000	50.600	74.213	0.440	13.665	13.665
692.000	51.600	75.680	0.733	22.774	22.774
694.000	52.000	76.267	0.293	9.110	9.110
696.000	52.400	76.853	0.293	9.110	9.110
698.000	53.300	78.173	0.660	20.497	20.497

TABLE A-2 (Cont.)

EPA HIGHWAY FUEL ECONOMY CYCLE (383 PTS)

TIME (SEC)	VELOCITY (MPH)	VELOCITY (FPS)	ACELERATION (FT/SEC**2)	FORCE (LBS)	TORQUE (FT*LBS)
700.000	54.200	79.493	0.660	20.497	20.497
702.000	54.800	80.373	0.440	13.665	13.665
704.000	55.500	81.400	0.513	15.942	15.942
706.000	56.100	82.280	0.440	13.665	13.665
708.000	56.400	82.720	0.220	6.832	6.832
710.000	56.700	83.160	0.220	6.832	6.832
712.000	57.000	83.600	0.220	6.832	6.832
714.000	57.700	84.627	0.513	15.942	15.942
716.000	58.800	86.240	0.807	25.052	25.052
718.000	59.200	86.827	0.293	9.110	9.110
720.000	58.800	86.240	-0.293	-9.110	-9.110
722.000	58.100	85.213	-0.513	-15.942	-15.942
724.000	57.300	84.040	-0.587	-18.219	-18.219
726.000	56.800	83.307	-0.367	-11.387	-11.387
728.000	56.200	82.427	-0.440	-13.665	-13.665
730.000	54.600	80.080	-1.173	-36.439	-36.439
732.000	53.700	78.760	-0.660	-20.497	-20.497
734.000	52.900	77.587	-0.587	-18.220	-18.220
736.000	52.000	76.267	-0.660	-20.497	-20.497
738.000	50.500	74.067	-1.100	-34.161	-34.161
740.000	48.500	71.133	-1.467	-45.549	-45.549
742.000	46.800	68.640	-1.247	-38.716	-38.716
744.000	44.200	64.827	-1.907	-59.213	-59.213
746.000	39.200	57.493	-3.667	-113.872	-113.872
748.000	32.600	47.813	-4.840	-150.310	-150.310
750.000	26.800	39.307	-4.253	-132.091	-132.091
752.000	21.500	31.533	-3.887	-120.704	-120.704
754.000	17.400	25.520	-3.007	-93.375	-93.375
756.000	12.400	18.187	-3.667	-113.872	-113.872
758.000	7.000	10.267	-3.960	-122.981	-122.981
760.000	3.300	4.840	-2.713	-84.265	-84.265
762.000	0.700	1.027	-1.907	-59.213	-59.213
764.000	0.0	0.0	-0.513	-15.942	-15.942
766.000	0.0	0.0	0.0	0.0	0.0
768.000	0.0	0.0	0.0	0.0	0.0
770.000	0.0	0.0	0.0	0.0	0.0
772.000	0.0	0.0	0.0	0.0	0.0
774.000	0.0	0.0	0.0	0.0	0.0
776.000	0.0	0.0	0.0	0.0	0.0
778.000	0.0	0.0	0.0	0.0	0.0

END OF DATA

APPENDIX B

THE GENERAL MOTORS TIRE PERFORMANCE CRITERIA BREAK-IN PROCEDURE

The General Motors TPC specifications include the details of the break-in schedule that is to be used in preconditioning new tires. This procedure has gained widespread acceptance in the tire industry and is commonly used in test work.

TIRF procedures are not identical to those used on the GM continuous, running-belt machine because of basic differences between the two facilities. In the case of the break-in procedure, the sole difference is that the TIRF schedule employs a velocity of 30 and 6 mph while all of the GM tests are conducted at 2 mph.

Tire break-in procedures specified by GM are as follows: "The tread of the tire is preconditioned before testing by operating the tire at 80% of the T&RA load for one minute at each slip angle of ± 1, ± 2 and ± 4 degrees. The tire is then subjected to 15-second vertical load sweeps from 0 to 1.6 times its T&RA load rating for slip angles of 0, ± 1, ± 2 and ± 4 degrees.

Break-in procedures used on TIRF are equivalent since the times allotted to each test condition are scaled inversely to the velocity. A test velocity of 30 mph is used in the first part of the break-in procedure with each slip angle maintained for a period of 4 seconds. The roadway velocity is then reduced to 6 mph and 5-second, linear load ramps are applied. The distance that the tire rolls in each test condition and the amount of work done on the tire are thus the same for each facility.

APPENDIX C

TEST FACILITY - A DESCRIPTION

A photograph of the TIRF facility is shown as the frontispiece to this report; a dimensional view of the facility is shown in Figure C-1. The primary features of the machine are (Reference 2):

A. Tire Positioning System

The tire, wheel, force sensing balance, and hydraulic motor to drive or brake the tire are mounted in the movable upper head. The head provides steer, camber, and vertical motions to the tire. These motions (as well as vertical loading) are servo controlled and programmable for maximizing test efficiency. The ranges of the position variables, the rates at which they may be adjusted, and other information are shown in Table C-1.

Table C-1
TIRF CAPABILITIES

CHARACTERISTIC	RANGE
TIRE SLIP ANGLE (α)	$\pm 30^{\circ}$*
TIRE INCLINATION ANGLE (γ)	$\pm 30^{\circ}$**
TIRE SLIP ANGLE RATE ($\dot{\alpha}$)	10°/sec
TIRE INCLINATION ANGLE RATE ($\dot{\gamma}$)	7°/sec
TIRE LOAD RATE (TYPICAL)	2000 lb/sec
TIRE VERTICAL POSITIONING RATE	2"/sec
ROAD SPEED (V)	0-200 mph
TIRE OUTSIDE DIAMETER	Up to 46"
TIRE TREAD WIDTH	24" MAX.
BELT WIDTH	28"

* Can be increased to 90° with special setup.

** Can be increased to 60° with special setup.

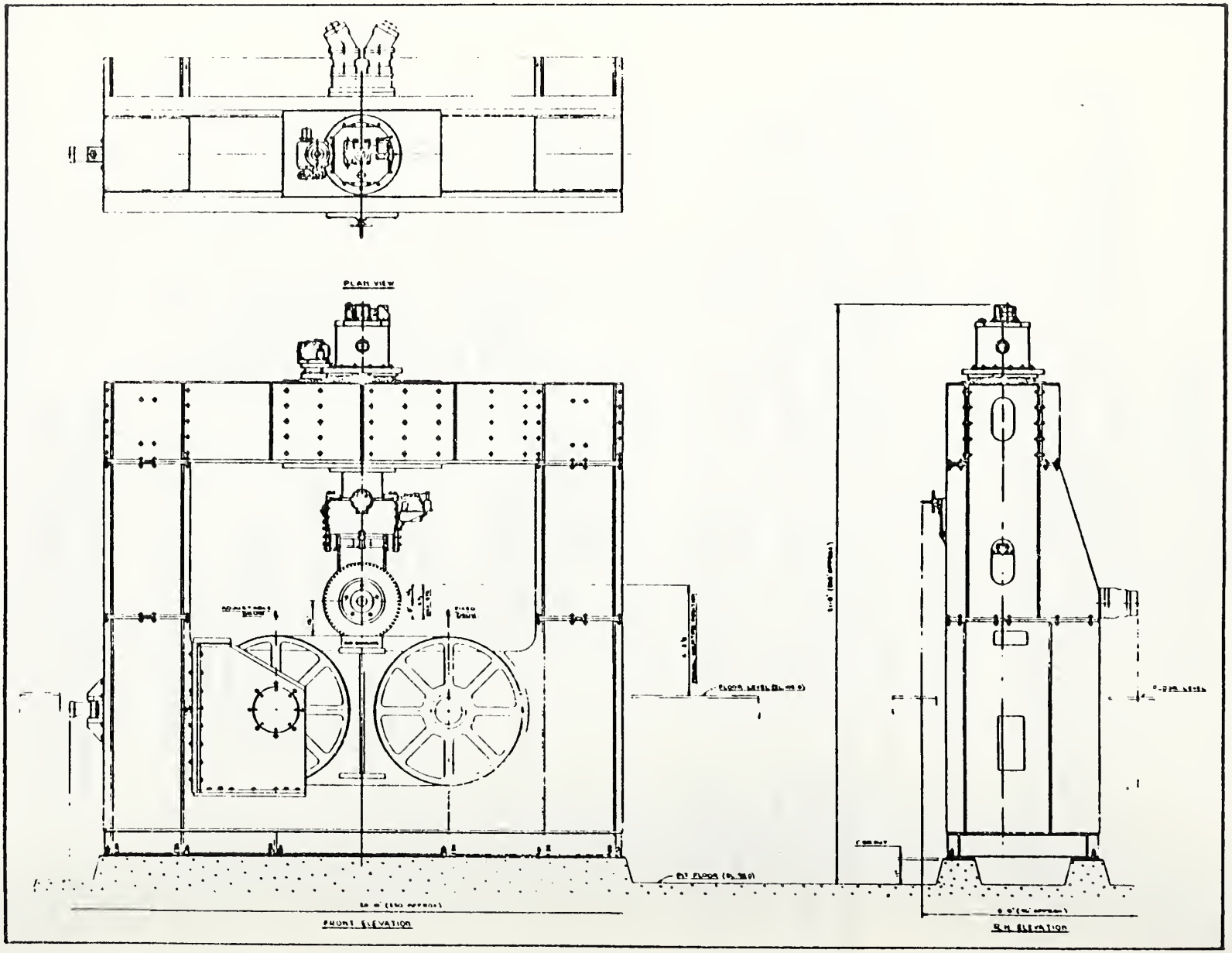


Figure C-1 TIRE RESEARCH MACHINE

B. Roadway

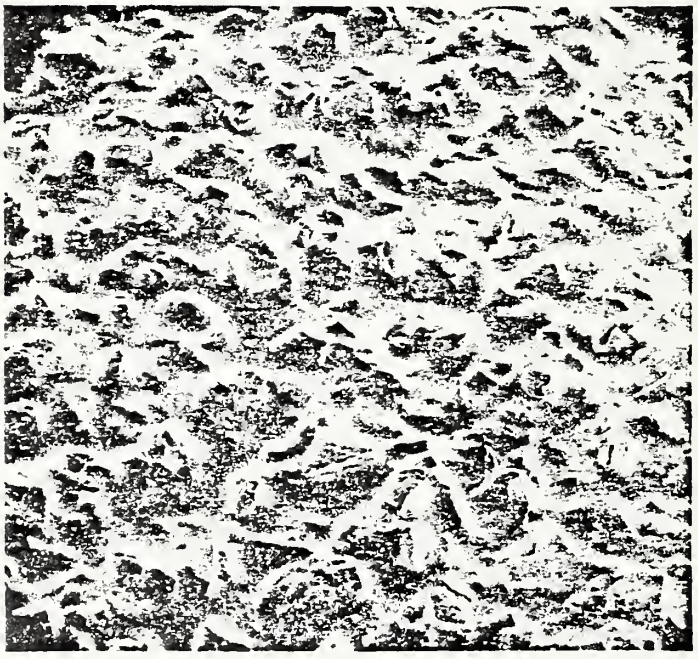
The 28-inch wide roadway is made up of a stainless steel belt covered with material that simulates the frictional properties of actual road surfaces. The belt is maintained flat to within 1 to 2 mils under the tire patch by the restraint provided by an air bearing pad which is beneath the belt in the tire patch region. The roadway is driven by one of the two 67-inch diameter drums over which it runs. The road speed is servo controlled; it may be programmed to be constant or varied.

The test surfaces used on TIRF are made from a commercially available proprietary material called Safety Walk.* The surface consists of a backing sheet treated with contact cement used to adhere it to the stainless steel belt. On the working side, a silicon carbide type of grit material is set in an epoxy type cement. This material is specified by its reflectance which we have found to be related to its microtexture and wet skid number. Standard practice is to use a surface with an initial wet skid number greater than the desired test value. The surface is then stoned with a grinding stone. The stoning serves to break off those sharp asperities which extend appreciably above the others. Stoned surfaces do not abrade the tire surfaces excessively, and they are stable under normal usage. Scanning Electron Microscope (SEM) photos have been taken of some of the surfaces used. Figure C-2 shows SEM photos of one of the materials used in both the "as received" and "after stoning" condition.

Schonfeld of the Ontario Ministry of Transportation and Communications has developed a method of photo-interpretation of pavement skid resistance (Reference 3). Samples of our material have been analyzed by Schonfeld who calculated skid numbers in general agreement with values which had been measured. The texture parameters used by Schonfeld are height, width, angularity, distribution and harshness of projections and the harshness of the surface between projections. He classified the surface in terms of the apparent height and angularity of the microprojections: polished, smooth, fine-grained, coarse-grained subangular, and coarse-grained angular. A fine-grained surface

* Manufactured by the 3M Company

a. AS RECEIVED



b. AFTER STONING

Figure C-2 SCANNING ELECTRON MICROSCOPE PHOTOS (15X) OF SAFETY WALK SURFACE

has microprojections approximately 1/4 mm high while coarse-grained surfaces (angular or subangular) have projections approximately 1/2 mm high or higher. The Safety Walk surfaces fall between fine-grained and coarse-grained with about two-thirds of the projections being more than 1/4 mm high.

A unique feature of TIRF is the ability to carry out tests under wet road conditions. A two-dimensional water nozzle spans the roadway. This nozzle has an adjustable throat which can be set to the desired water depth. The flow through the nozzle is then varied by controlling the water pressure. At each test condition the water film is laid on tangential to the belt at belt velocity. The film thickness may be varied from as low as 0.005 inches up to 0.5 inches.

C. Tire-Wheel Drive and Balance System

A drive system which is independent of the roadway drive is attached to the tire-wheel shaft. This separate drive allows full variation of tire slip both in the braking and driving modes. The tire slip ratio, referenced to road speed, is under servo control.

A six-component strain gage balance surrounds the wheel drive shaft. Three orthogonal forces and three corresponding moments are measured through this system. A fourth moment, torque, is sensed by a torque link in the wheel drive shaft. The load ranges of the basic passenger car and truck tire balances are shown in Table C-2. Transfer of forces and moments from the balance axis-system to the conventional SAE location at the tire-roadway interface is in the data reduction computer program.*

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* More detailed information on the balance systems and their calibration may be found in Reference 2.

Table C-2

BALANCE SYSTEM CAPABILITY

COMPONENT	PASSENGER CAR TIRE BALANCE	TRUCK TIRE BALANCE
TIRE LOAD (L)	4000 lb	12,000 lb
TIRE TRACTIVE FORCE	±4000 lb	± 9000 lb
TIRE SIDE FORCE	±4000 lb	± 8000 lb
TIRE SELF ALIGNING TORQUE	±500 lb ft	± 1000 lb ft
TIRE OVERTURNING MOMENT	±1000 lb ft	± 2000 lb ft
TIRE ROLLING RESISTANCE MOMENT	±200 lb ft	± 400 lb ft

D. System Operation

1. Data Acquisition Program (DAP) Control

The data acquisition program (DAP) is a software system which controls machine operation and logs data during tests. DAP controls test operations by means of discrete setpoints which are generated in the computer by the program. These setpoints are sent to the machine servos which respond and establish tire test conditions. After the setpoints are sent to the servos, a delay time is provided which starts after the machine variables have reached a steady state value within predetermined tolerances. This allows the system to stabilize before data are taken. After data are taken, the next set of test conditions is established and testing continues.

One or two variables can be changed during DAP testing. The other test parameters are kept fixed throughout the test. Up to twenty data points can be used for each variable in a run.

A data reduction program is used to operate on the raw data collected during testing. These new data are reduced to forces and moments in the proper axis system and all variables are scaled to produce quantities

with engineering units. Raw and reduced data are temporarily stored in a disc file. Both reduced and raw data can be transferred to magnetic tape and maintained as a permanent record.

Reduced data points can be listed, plotted and curves can be fitted to the points. All of the standard Calspan plots can be generated from DAP test data.

Data lists and plots are displayed on the oscilloscope screen of a CRT console. Hard copies of this information can be made off this display.

2. Continuous Sampling Program (CSP) Control

The continuous sampling program (CSP) is a software system which controls machine operation and continuously logs data during tests. Test variables can be constant or changed at rapid rates. One or all variables can be changed during a test. Data can be sampled at rates up to 100 samples per second. Pauses are used so that data can be logged during desired intervals of the test.

CSP testing can be conducted quickly which in turn reduces tire wear during severe tests. The high rate of data sampling also permits limited dynamic measurements to be made during testing.

Two parameter plots of data can be made. Carpet and family plots of test data cannot be made with this program at the present time. CSP data will also reflect time effects if tire characteristics are a function of the rate of change of testing variables.

Data reduction is accomplished in a manner similar to that employed in DAP testing.

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